MODULE FOR GENERAL PHYSICS (Phys 1011)

Ministry of Science and Higher Education

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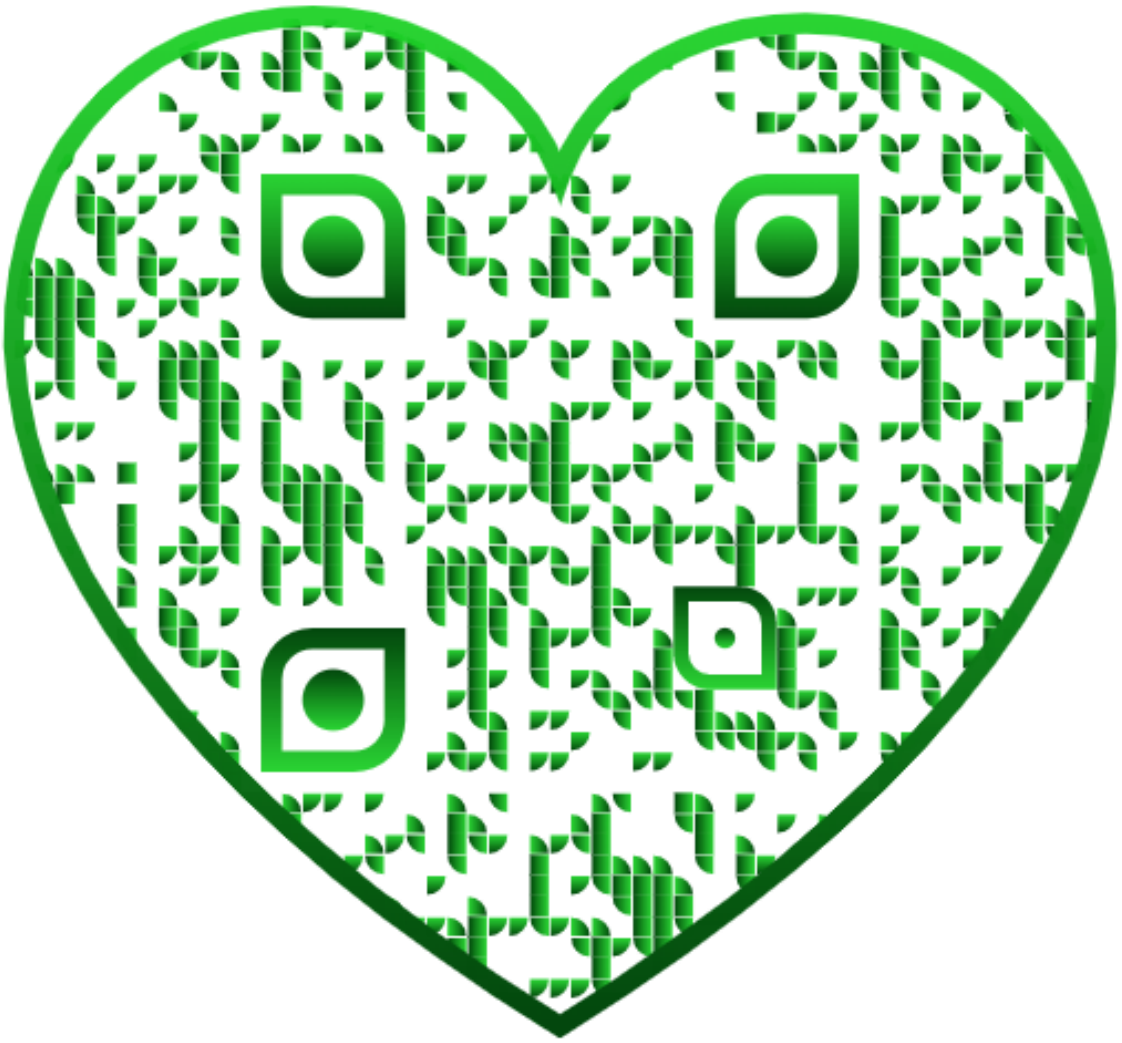

MODULE OVERVIEW

The module provides students with a firm foundation in the role of physics in different science, technology and engineering fields together with mathematics and problem-solving skills. And also it prepares students to know the applications of physics in multidisciplinary areas that are at the forefront of technology in 21st Century, such as agricultural and archeological sciences, health and medical sciences, earth and space sciences, electronics and electromagnetism, communication technology, energy systems, and other related engineering and science fields that require a very solid background in physics.

This module will be taught in an introductory undergraduate level and is primarily designed for a broader audience of science students. The goal of the course is to give an overview of the various physics based analysis and dating techniques used in science and technology. High school mathematics and physics concepts are enough as prerequisite for this course. Laws, principles, and methods of physics will be taught in a more descriptive manner using simple mathematics. The course covers preliminaries, mechanics, fluid mechanics, electromagnetism and electronics, thermodynamics, oscillations and waves, and cross-cutting applications of physics in different areas of science and technology. For this course a total of 10 experiments relevant to Mechanics, Electricity and Magnetism, and Electronics will be carried out.

I. List of Experiments from Mechanics
   - Measurements of basic constants, length, .mass and time
   - Free fall
   - Hook's law
   - Density of liquids
   - Simple pendulum

II. List of Experiments from Electricity and Magnetism
   - Calibration of voltmeter and ammeter from galvanometer
   - Ohm's law, parallel and series combination of resistors

III. List of Experiments from electronics
   - V-I characteristics of diode

- Rectification
- Logic gate

From these recommended experiments, at least six experiments to be performed. Simulation experiments from the Internet can be used to supplement laboratory activities whenever possible. Manuals for the experiments will be prepared at the respective Universities. It is recommended that the number of students per laboratory session to be between 25 and 30.

Module Objectives:

Upon completion of this module students should be able to:

- Discuss basic physics by refreshing and summarizing the previous preparatory physics concepts before tackling the advanced physics courses.
- Explain the kinematics and dynamics of particles in one and two dimensions.
- State principles of fluids in equilibrium and solve problems applying Pascal's principle, Archimedes's, principles and Bernoulli's equation in various situations.
- Explain the basic concepts of charges, fields and potentials.
- Analyze direct and alternating current circuits containing different electric elements and solve circuit problems.
- Demonstrate the use and the working system of cells (batteries), resistors, generators, motors and transformers.
- Explain the first law of thermodynamics for a closed system and apply it to solve problems.
- Discuss systems that oscillate with simple harmonic motion.
- Explain the application of physics in different sciences and technology fields.
- Apply and describe a variety of experimental techniques and grasp the general guidelines of laboratory.
- Develop the skill of laboratory work.

ACKNOWLEDGEMENT

In performing our module writing task, we had to take the help and guideline of some respected persons, who deserve our greatest gratitude. The completion of this assignment gives us much Pleasure. We would like to show our deepest gratitude to Dr. Eba Mijena, Director General for Academic and Research of Ministry of Science and Higher Education (MoSHE), for giving us a good guideline for write up and completion of the module throughout numerous consultations. We would also like to expand our deepest gratitude to all those who have directly and indirectly participated in writing this module.

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TABLE OF CONTENTS

MODULE OVERVIEW ii

ACKNOWLEDGEMENT iv

CHAPTER ONE 1

PRELIMINARIES 1

1.1. Physical Quantities and Measurement 1

1.1.1. Physical quantities 2

1.1.2. SI Units: Basic and Derived Units 3

1.1.3. Conversion of Units 3

1.2. Uncertainty in Measurement and Significant Digits 4

1.2.1. Significant digits 6

1.3. Vectors: composition and resolution 8

1.3.1. Vector Representation 8

B. Geometric Method 8

1.3.2. Vector Addition 9

B. Parallelogram law of vector addition 9

1.3.3. Components of Vector 9

1.4. Unit Vector 11

1.4.2. Finding a Unit Vector 12

CHAPTER TWO 15

KINEMATICS AND DYNAMICS OF PARTICLES 15

2.1. Kinematics in One and Two Dimensions 16

2.1.1. Displacement, velocity and Acceleration in 1D and 2D 16

2.1.2. Motion with Constant Acceleration 18

2.1.3. Free Fall Motion 21

2.1.4. Projectile Motion 22

2.2. Particle Dynamics and Planetary Motion 26

2.2.1. The Concept of Force as A Measure of Interaction 27

2.2.2. Type of Forces 27

2.2.3. Newton's Laws of Motion and Applications 29
2.2.4. Uniform Circular Motion 37
2.2.5. Newton's Law of Universal Gravitation 38
2.2.6. Kepler's Laws, Satellites Motion and Weightlessness 40
2.3. Work, Energy and Linear Momentum 43
2.3.1. Work and Energy 44
2.3.2. Power 50
2.3.3. Linear Momentum 51
2.3.4. Collisions 53
2.3.5. Center of Mass 56
CHAPTER THREE 62
FLUID MECHNICS 62
3.1. Properties of Bulk Matter 62
3.2. Density and Pressure in Static Fluids 68
3.3. Buoyant Force and Archimedes' Principles 70
3.3.1. Archimedes' principle 72
3.4. Moving Fluids and Bernoulli Equations (Fluid Dynamics) 73
3.4.1. Bernoulli's Equation 74
CHAPTER FOUR 80
HEAT AND THERMODYNAMICS 80
4.1. The concept of Temperature and the Zeroth law of Thermodynamics 80
4.2. Thermal Expansion 83
4.3. The Concept of Heat, Work and Internal Energy 85
4.4. Specific Heat and Latent Heat 86
4.5. Heat Transfer Mechanisms 89
4.6. The First Law of Thermodynamics 92
CHAPTER FIVE 99
OSCILLATIONS, WAVES AND OPTICS 99
5.1. Simple Harmonic Motion 99
5.1.1. Periodic and Oscillatory Motion 100
5.1.2. Displacement, Velocity and Acceleration in a SHM 103
5.2. The simple Pendulum 104

5.3. Wave and Its Characteristics 106
5.4. Resonance 108
5.5. The Doppler Effect 108
5.6. Image Formation by Thin Lenses and Mirrors 111
CHAPTER SIX 119
ELECTROMAGNETISM AND ELECTRONICS 119
6.1. Coulomb's Law and Electric Fields 120
6.2. Electric Potential 125
6.3. Current, Resistance and Ohm's Law 130
6.4. Electrical Energy and Power 134
6.5. Equivalent Resistance and Kirchhoff's Rule 134
6.6. Magnetic Field and Magnetic Flux 140
6.7. Electromagnetic Induction 144
6.8. Insulators, Conductors and Semiconductors 146
6.9. Diodes 154
6.10. Transistors 158
CHAPTER SEVEN 166
CROSS CUTTING APPLICATIONS OF PHYSICS 166
7.1. Physics in Agriculture and Environment 168
7.2. Physics in Industries 172
7.3. Physics in Health Sciences and Medical Imaging 173
7.3. Physics and Archeology 177
7.4. Application in Earth and Space Sciences 181
7.5. Applications in Power Generation 184
REFERENCES 193

CHAPTER ONE

PRELIMINARIES

The word physics comes from the Greek word meaning “nature”. Today physics is treated as the base for science and have various applications for the ease of life. Physics deals with matter in relation to energy and the accurate measurement of natural phenomenon. Thus physics is inherently a science of measurement. The fundamentals of physics form the basis for the study and the development of engineering and technology.

Measurement consists of the comparison of an unknown quantity with a known fixed quantity. The quantity used as the standard of measurement is called ‘unit’. For example, a vegetable vendor weighs the vegetables in terms of units like kilogram.

Learning Objectives: At the end of this chapter, you will be able to:

- Explain physics.
- Describe how SI base units are defined.
- Describe how derived units are created from base units.
- Express quantities given in SI units using metric prefixes.
- Describe the relationships among models, theories, and laws.
- Know the units used to describe various physical quantities.
- Become familiar with the prefixes used for larger and smaller quantities.
- Master the use of unit conversion (dimensional analysis) in solving problems.
- Understand the relationship between uncertainty and the number of significant figures in a number.

1.1. Physical Quantities and Measurement

Self Diagnostic Test:

- Why do we need measurement in physics and our day-to-day lives?
- Give the names and abbreviations for the basic physical quantities and their corresponding SI units.
- What do you mean by a unit?

Definitions:

Physical quantity is a quantifiable or assignable property ascribed to a particular phenomenon or body, for instance the length of a rod or the mass of a body.

Measurement is the act of comparing a physical quantity with a certain standard.

Scientists can even make up a completely new physical quantity that has not been known if necessary. However, there is a set of limited number of physical quantities of fundamental importance from which all other possible quantities can be derived. Those quantities are called **Basic Physical Quantities**, and obviously the other derivatives are called **Derived Physical Quantities.**

1.1.1. Physical quantities

A. Basic Physical Quantities:

Basic quantities are the quantities which cannot be expressed in terms of any other physical quantity. Example: length, mass and time.

B. Derived Physical Quantities:

Derived quantities are quantities that can be expressed in terms of fundamental quantities. Examples: area, volume, density.

Giving numerical values for physical quantities and equations for physical principles allows us to understand nature much more deeply than qualitative descriptions alone. To comprehend these vast ranges, we must also have accepted units in which to express them. We shall find that even in the potentially mundane discussion of meters, kilograms, and seconds, a profound simplicity of nature appears: all physical quantities can be expressed as combinations of only seven basic physical quantities.

We define a **physical quantity** either by specifying how it is measured or by stating how it is calculated from other measurements. For example, we might define distance and time by specifying methods for measuring them, such as using a meter stick and a stopwatch. Then, we could define *average speed* by stating that it is calculated as the total distance traveled divided by time of travel.

Measurements of physical quantities are expressed in terms of **units**, which are standardized values. For example, the length of a race, which is a physical quantity, can be expressed in units of meters (for sprinters) or kilometers (for distance runners). Without standardized units, it would be extremely difficult for scientists to express and compare measured values in a meaningful way.

1.1.2. SI Units: Basic and Derived Units

SI unit is the abbreviation for **International System of Units** and is the modern form of metric systemfinallyagreeduponattheeleventhInternationalconferenceofweightsandmeasures,1960. This system of units is now being adopted throughout the world and will remain the primary system of units of measurement. SI system possesses features that make it logically superior to any other system and it is built upon 7 basic quantities and their associated units (see Table 1.1).

Table 1.1: Basic quantities and their SI units

Property	Symbol	Unit	Dimension
Length	L	meter (m)	L
Mass	m	kilogram (kg)	M
Time	t	second (s)	T
Temperature	T	kelvin (K)	θ
Electric Current	I	ampere (A)	I
Amount of Substance	N	mole (N)	1
Luminous Intensity	F	candela (cd)	J

Table 1.2: Derived quantities, their SI units and dimensions

Property	Symbol	Unit	Dimension
Force	F	newton (N)	$\mathrm{kg{\cdot}m{\cdot}s^{-2}} = \mathrm{kg{\cdot}m{\cdot}/s^2}$
Speed	v	meter per second (m/s)	$\mathrm{m{\cdot}s^{-1}} = \mathrm{m/s}$
Pressure	P	pascal (Pa)	(force per unit area) $\mathrm{kg{\cdot}m^{-1}{\cdot}s^{-2}}$
Energy	E	joule (J)	$\mathrm{kg{\cdot}m^2{\cdot}s^{-2}}$
Power	W	watt (W)	(energy per unit time) $\mathrm{kg{\cdot}m^2{\cdot}s^{-3}}$

1.1.3. Conversion of Units

Measurements of physical quantities are expressed in terms of *units*, which are standardized values. To convert a quantity from one unit to another, multiply by conversions factors in such a

way that you cancel the units you want to get rid of and introduce the units you want to end up with. Below is the table for commonly used unit conversions (see Table 1.3).

Table 1.3: Unit conversion of basic quantities

Quantity	From	To	Operation
Length	inch (in)	m	$(\text{inch}) \times 0.0254$
	foot (ft)	m	$(\text{foot}) \times 0.3048$
	mile (mi)	m	$(\text{mile}) \times 1609.34$
Mass	pound (lb)	kg	$(\text{pound}) \times 0.4536$
	metric ton (t)	kg	$(\text{ton}) \times 1000$
	ounce	kg	$(\text{ounce}) \times 0.02835$
Volume	liter (l)	m^3	$(liter) \times 0.001$
	gallon (ga)	m^3	$(\text{gallon}) \times 0.00379$
Temperature	fahrenheit (F)	K	$\{(\text{fahrenheit}) - 32\} \times \frac{5}{9} + 273.15$
	celcius (C)	K	$(\text{celcius}) + 273.15$

Examples:

1. Length 0.02in can be converted into SI unit in meters using table 1.3 as follow:

   Solution:

   0.02in= 0.02 x0.0254m = 0.000508m = 5.08 $x10^{-4}$m = 0.503 mm or 508µm.

2. Honda Fit weighs about 2,500 lb. It is equivalent to 2500 x0.4536kg = 1134.0kg.

Activities:

1. A common Ethiopian cities speed limit is 30km/hr. What is this speed in miles per hours?
2. How many cubic meters are in 250,000 cubic centimeters?
3. The average body temperature of a house cat is 101.5oF. What is this temperature in Celsius?

1.2. Uncertainty in Measurement and Significant Digits

Measurements are always uncertain, but it was always hoped that by designing a better and better experiment we can improve the uncertainty without limits. It turned out not to be the case. No measurement of a physical quantity can be entirely accurate. It is important to know, therefore, just how much the measured value is likely to deviate from the unknown, true, value of the quantity. The art of estimating these deviations should probably be called uncertainty analysis,

but for historical reasons is referred to as error analysis. This document contains brief discussions about how errors are reported, the kinds of errors that can occur, how to estimate random errors, and how to carry error estimates into calculated results.

Uncertainty gives the range of possible values of the measure and, which covers the true value of the measure and. Thus uncertainty characterizes the spread of measurement results. The interval of possible values of measure and is commonly accompanied with the confidence level. Therefore, the uncertainty also indicates a doubt about how well the result of the measurement presents the value of the quantity being measured.

All measurements always have some uncertainty. We refer to the uncertainty as the error in the measurement. Errors fall into two categories:

1. **Systematic Error** - errors resulting from measuring devices being out of calibration. Such measurements will be consistently too small or too large. These errors can be eliminated by pre-calibrating against a known, trusted standard.
2. **Random Errors** - errors resulting in the fluctuation of measurements of the same quantity about the average. The measurements are equally probable of being too large or too small. These errors generally result from the fineness of scale division of a measuring device.

Physics is an empirical science associated with a lot of measurements and calculations. These calculations involve measurements with uncertainties and thus it is essential for science students to learn how to analyze these uncertainties (errors) in any calculation. Systematic errors are generally "simple" to analyze but random errors require a more careful analysis and thus it will be our focus. There is a statistical method for calculating random uncertainties in measurements. The following general rules of thumb are often used to determine the uncertainty in a single measurement when using a scale or digital measuring device.

1. Uncertainty in a scale measuring device is equal to the smallest increment divided by 2.

$$\sigma_x = \frac{Smallest\ increament}{2}$$

Example: Meter Stick (scale device)

$$\sigma_x = \frac{1mm}{2} = 0.5mm = 0.05cm$$

2. Uncertainty in a digital measuring device is equal to the smallest increment.

$$\sigma_x = smallest\ increament$$

Example: A reading from digital Balance (digital device) is 5.7513 kg, therefore

$$\sigma_x = 0.0001$$

When stating a measurement, the uncertainty should be stated explicitly so that there is no question about it. However, if it is not stated explicitly, an uncertainty is still implied. For example, if we measure a length of 5.7cm with a meter stick, this implies that the length can be anywhere in the range 5.65 cm ≤ L ≤ 5.75 cm. Thus, L =5 .7cm measured with a meter stick implies an uncertainty of 0.05 cm. A common rule of thumb is to take one-half the unit of the last decimal place in a measurement to obtain the uncertainty. In general, any measurement can be stated in the following preferred form:

Measurement = $x_{best} \pm \sigma_x$

Where, x_{best}= best estimate of measurement, σ_x= uncertainty (error) in measurement.

1.2.1. Significant digits

Whenever you make a measurement, the number of meaningful digits that you write down implies the error in the measurement. For example if you say that the length of an object is 0.428 m, you imply an uncertainty of about 0.001 m. To record this measurement as either 0.4 or 0.42819667 would imply that you only know it to 0.1m in the first case or to 0.00000001 m in the second. You should only report as many significant figures as are consistent with the estimated error. The quantity 0.428m is said to have three significant digits, that is, three digits that make sense in terms of the measurement. Notice that this has nothing to do with the "number of decimal places". The same measurement in centimeters would be 42.8cm and still be a three significant figure. The accepted convention is that only one uncertain digit is to be reported for a measurement. In the example if the estimated error is 0.02m you would report a result of 0.43 ± 0.02 m, not 0.428 ± 0.02 m.

Students frequently are confused about when to count a zero as a significant figure. The rule is: If the zero has a non-zero digit anywhere to its left, then the zero is significant, otherwise it is not. For example 5.00 has 3 significant figures; the number 0.0005 has only one significant

figure, and 1.0005 has 5 significant figures. A number like 300 is not well defined. Rather one should write 3 x 10^2, one significant figure, or 3.00 x 10^2, 3 significant figures.

When writing numbers, zeros used ONLY to help in locating the decimal point are NOT significant others are. See the following examples:

1) 0.0062 cm has 2 significant figures

2) 4.0500 cm has 5 significant figures

Rules for significant digits:

Rule 1: When approximate numbers are multiplied or divided, the number of significant digits in the final answer is the same as the number of significant digits in the least accurate of the factors.

Example: $X = \frac{45}{(3.22m)x(2.005m)} = 6.97015\ \frac{N}{m^2}$.

Least significant factor (45) has only two (2) digits so only two are justified in the answer. The appropriate way to write the answer is P = 7.0 N/m^2.

Rule 2: When approximate numbers are added or subtracted, the number of significant digits should equal the smallest number of decimal places of any term in the sum or difference.

Example: 9.65 cm + 8.**4** cm - 2.89 cm = 15.**1**6 cm

Note that the ***least precise*** measure is **8.4**cm. Thus, answer must be to nearest ***tenth*** of cm even though it requires 3 significant digits. The appropriate way to write the answer is 15.2cm.

Example: Find the area of a metal plate that is 8.71 cm by 3.2 cm.

A = LW = (8.71 cm) (3.2 cm) = 27.872 cm^2

In general to determine significant digits in a given number

1. All non-zero numbers are significant.
2. Zeros within a number are always significant.
3. Zeros that do nothing but set the decimal point are not significant. Both 0.000098 and 0.98 contain two significant figures.
4. Zeros that aren't needed to hold the decimal point are significant. For example, 4.00 has three significant figures.
5. Zeros that follow a number *may* be significant.

1.3. Vectors: composition and resolution

A **scalar** is a quantity that is completely specified by a number and unit. It has magnitude but no direction. Scalars obey the rules of ordinary algebra. Examples: mass, time, volume, speed, etc. A **vector** is a quantity that is specified by both a magnitude and direction in space. Vectors obey the laws of vector algebra. Examples are: displacement, velocity, acceleration, momentum, etc.

1.3.1. Vector Representation

A. Algebraic Method

Vectors are represented algebraically by a letter (or symbol) with an arrow over its head (Example: velocity by $\vec{v}$, momentum by $\vec{p}$) and the magnitude of a vector is a positive scalar and is written as either by |**A**| or *A*.

B. Geometric Method

When dealing with vectors it is often useful to draw a picture (line with an arrow). Here is how it is done:

- Vectors are nothing but straight arrows drawn from one point to another.
- Zero vector is just a vector of zero length - a point.
- Length of vectors is the magnitude of vectors. The longer the arrow the bigger the magnitude.
- It is assumed that vectors can be parallel transported around. If you attach beginning of vector $\vec{A}$to end of another vector $\vec{B}$then the vector $\vec{A}$+$\vec{B}$is a straight arrow from begging of vector$\vec{A}$to end of vector $\vec{B}$.

A vector changes if its magnitude or direction or if both magnitude and direction change. We add, subtract or equate physical quantities of same units and same characters (all the terms on both sides of an equation must be either scalar or vector). A vector may be multiplied by a pure number or by a scalar. Multiplication by a pure number merely changes the magnitude of the vector. If the number is negative, the direction is reversed. When a vector is multiplied by a scalar, the new vector also becomes a different physical quantity. For example, when velocity, a vector, is multiplied by time, a scalar, we obtain a displacement.

1.3.2. Vector Addition

A single vector that is obtained by adding two or more vectors is called **resultant vector** and it is obtained using the following two methods

A. Graphical method of vector addition

Graphically vectors can be added by joining their head to tail and in any order their resultant vector is the vector drawn from the tail of the first vector to the head of the last vector. In Figure 1 graphical technique of vector addition is applied to add three vectors. The resultant vector **R** = **A** + **B** + **C** is the vector that completes the polygon. In other words, **R** is the vector drawn from the tail of the first vector to the tip of the last vector

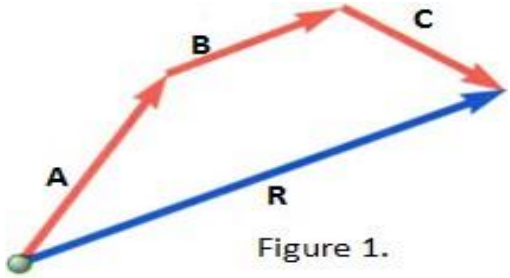


Figure 1.

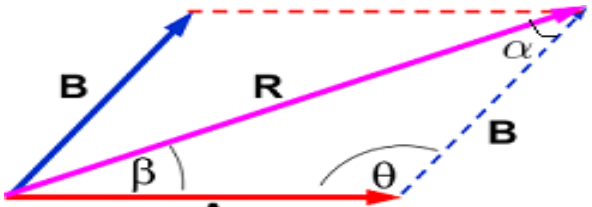


Figure 2. Parallelogram law of vector addition

B. Parallelogram law of vector addition

The parallelogram law states that the resultant **R** of two vectors **A** and **B** is the **diagonal** of the **parallelogram** for which the two vectors **A** and **B** becomes adjacent sides. All three vectors **A**, **B** and **R** are concurrent as shown in Figure 2. **A** and **B** are also called the components of **R**. The magnitude of the diagonal (resultant vector) is obtained using cosine law and direction (i.e. the angle that the diagonal vector makes with the sides) is obtained using the sine law.
Applying cosine and sine laws for the triangle formed by the two vectors:

Cosine law: $\boldsymbol{R = \sqrt{A^2 + B^2 - 2ABcos\theta}}$

Sine law: $\frac{\boldsymbol{sin\theta}}{\boldsymbol{R}} = \frac{\boldsymbol{sin\alpha}}{\boldsymbol{A}} = \frac{\boldsymbol{sin\beta}}{\boldsymbol{B}}$

1.3.3. Components of Vector

Considering Figure 3 below, components of the given vector **A** are obtained by applying the trigonometric functions of sine and cosine.

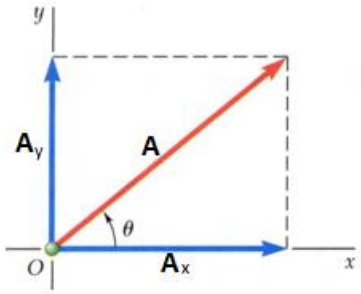


Figure 3: Components of vector **A**

$cos\theta = \frac{A_x}{A} \implies A_x = Acos\theta$ …….. is the x component of **A**

$sin\theta = \frac{A_y}{A} \implies A_y = Asin\theta$ ……. Is the y component of **A**

The components $\mathbf{A}_x$ and $\mathbf{A}_y$can be added to give back **A** as their resultant.

$$\mathbf{A} = \mathbf{A}_x + \mathbf{A}_y$$

Because $\mathbf{A}_x$ and $\mathbf{A}_y$ are perpendicular to each other, the magnitude of their resultant vector is obtained using Pythagoras theorem.

$$A = \sqrt{A_x^2 + A_y^2}$$

Similarly, any three dimensional vector **A** can be written as the sum of its *x, y and z* components.

$$\mathbf{A} = \mathbf{A}_x + \mathbf{A}_y + \mathbf{A}_z$$

And its magnitude becomes

$$A = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

The direction angles that this vector makes with the three axes, is given by the **direction of cosines.**

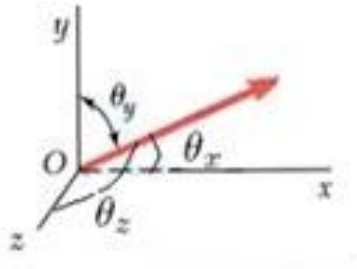


Figure 4: Vector in three dimensional space

$$Cos\theta_x = \frac{A_x}{A} \qquad \Longrightarrow \qquad \theta_x = \cos^{-1}\left(\frac{A_x}{A}\right)$$

$$Cos\theta_y = \frac{A_y}{A} \qquad \Longrightarrow \qquad \theta_y = \cos^{-1}\left(\frac{A_y}{A}\right)$$

$$Cos\theta_z = \frac{A_z}{A} \qquad \Longrightarrow \qquad \theta_z = \cos^{-1}\left(\frac{A_z}{A}\right)$$

1.4. Unit Vector

A unit vector is a vector that has magnitude of one and it is dimensionless and its sole purpose is to point a given vector in specified direction. It is usually denoted with a "hat".

$$\boldsymbol{A} = A\hat{u}$$

There is a special set of three unit vectors that are exceptionally useful for problems involving vectors, namely the Cartesian coordinate axis unit vectors. There is one of them for each positive coordinate axis direction. These unit vectors are so prevalent that we give them special names. For a two-dimensional x-y coordinate system we have the unit vector $\hat{\imath}$ pointing in the +x direction, and, the unit vector $\hat{\jmath}$ pointing in the +y direction. For a three-dimensional x-, y- and z-coordinate system, we have those two, and one more, namely the unit vector $\hat{k}$ pointing in the +z direction.

Any vector can be expressed in terms of unit vectors. Consider, for instance, a vector **A** with components A_x, A_y, and A_z. The vector formed by the product $A_x\hat{\imath}$ has magnitude $|A_x|$ in the +x direction. This means that $A_x\hat{\imath}$ isthe x-component of vector **A.** Similarly, $A_y\hat{\jmath}$is the y-component of vector **A** and, $A_z\hat{k}$ is the z-component vector of **A**. Thus **A** can be expressed as:

$$\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}$$

The vector $\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}$ is depicted in the figure 4above, along with the vectors $A_x\hat{\imath}$, $A_y\hat{\jmath}$, and $A_z\hat{k}$drawn so that is clear that the three of them add up to $\vec{A}$.

1.4.1. Vector addition in Unit Vector Notation

Adding vectors that are expressed in unit vector notation is easy in that individual unit vectors appearing in each of two or more terms can be factored out. The concept is best illustrated by means of an example.

Let$\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}$ and $\vec{B} = B_x\hat{\imath} + B_y\hat{\jmath} + B_z\hat{k}$

$$\vec{A} + \vec{B} = (A_x + B_x)\hat{\imath} + \left(A_y + B_y\right)\hat{\jmath} + (A_z + B_z)\hat{k}$$

We see that the sum of vectors that are expressed in unit vector notation is simply the sum of the x components times $\hat{\imath}$, plus the sum of the y components times $\hat{\jmath}$, plus the sum of the z component times $\hat{k}$.

1.4.2. Finding a Unit Vector

Consider the vector $\vec{r} = x\hat{\imath} + y\hat{\jmath} + z\hat{k}$

The unit vector r̂ in the same direction as the vector $\vec{r}$is simply the vector $\vec{r}$divided by itsmagnitude *r*. Or

$$\vec{r} = \frac{\vec{r}}{r} = \frac{x\hat{\imath} + y\hat{\jmath} + z\hat{k}}{r} = \frac{x}{r}\hat{\imath} + \frac{y}{r}\hat{\jmath} + \frac{z}{r}\hat{k}$$

The result makes it clear that each component of the unit vector is simply the corresponding component, of the original vector, divided by the magnitude $r = \sqrt{x^2 + y^2 + z^2}$of the original vector.

Chapter Summery

Physical quantity is the property of an object that can be quantified.

Measurement is the act of comparing a physical quantity with its unit.

Basic quantities are the quantities which cannot be expressed in terms of any other physical quantity. Example: length, mass and time.

Derived quantities are quantities that can be expressed in terms of fundamental quantities. Example: area, volume, density.

Uncertainty gives the range of possible values of the measure and, which covers the true value of the measure and thus uncertainty characterizes the spread of measurement results.

A **scalar** is a quantity that is completely specified by a number and its unit. It has magnitude but no direction. Scalars obey the rules of ordinary algebra. Examples: mass, time, volume,

A **vector** is a quantity that is specified by both a magnitude and direction in space.

Vector **can be represented either by** Algebraic method **or** Geometric method.

A single vector that is obtained by adding two or more vectors is called **resultant vector** and it is obtained using the following two methods

Vectors can be added using the ways **Graphical method of vector addition** or **Parallelogram law of vector addition.**

A unit vector is a vector that has magnitude of one and it is dimensionless and a sole purpose of unit vector is to point-that is, to specify a direction. It is usually denoted with a “hat”.

Chapter Review Questions and Problems

1. Vector $\vec{A}$ has magnitude of 8units and makes an angle of 45^0 with the positive x-axis. Vector $\vec{B}$ also has the same magnitude of 8units and directed along the negative x-axis. Find
   a. The magnitude and direction of $\vec{A} + \vec{B}$
   b. The magnitude and direction of $\vec{A} - \vec{B}$
2. Given the displacement vectors $\vec{A} = 3\hat{\imath} - 4\hat{\jmath} + 4\hat{k}$, $\vec{B} = 2\hat{\imath} + 3\hat{\jmath} - 7\hat{k}$. Find the magnitudes of the vectors a) $\vec{A}$+$\vec{B}$ b) 2$\vec{A}$-$\vec{B}$
3. If $\vec{A} = 6\hat{\imath} - 8\hat{\jmath}$, $\vec{B} = -8\hat{\imath} + 3\hat{\jmath}and\vec{C} = 26\hat{\imath} + 19\hat{\jmath}$. Find a and b Such that $a\vec{A}$ +b$\vec{B}$ + $\vec{C} = 0$
4. Find a unit vector in the direction of the resultant of vectors $\vec{A} = 2\hat{\imath} - 3\hat{\jmath} + \hat{k}$, $\vec{B} = \hat{\imath} + \hat{\jmath} + 2\hat{k}$ and $\vec{C} = 3\hat{\imath} - 2\hat{\jmath} + 4\hat{k}$

CHAPTER TWO

KINEMATICS AND DYNAMICS OF PARTICLES

Mechanics is the study of the physics of motions and how it relates to the physical factors that affect them, like force, mass, momentum and energy. Mechanics may be divided into two branches: Dynamics, which deals with the motion of objects with its cause – force; and kinematics describes the possible motions of a body or system of bodies without considering the cause. Alternatively, mechanics may be divided according to the kind of system studied. The simplest mechanical system is the particle, defined as a body so small that its shape and internal structure are of no consequence in the given problem. More complicated is the motion of a system of two or more particles that exert forces on one another and possibly undergo forces exerted by bodies outside of the system.

The principles of mechanics have been applied to three general realms of phenomena. The motions of such celestial bodies as stars, planets, and satellites can be predicted with great accuracy thousands of years before they occur. As the second realm, ordinary objects on Earth down to microscopic size (moving at speeds much lower than that of light) are properly described by mechanics without significant corrections. The engineer who designs bridges or aircraft may use the Newtonian laws of mechanics with confidence, even though the forces may be very complicated, and the calculations lack the beautiful simplicity of celestial mechanics. The third realm of phenomena comprises the behavior of matter and electromagnetic radiation on the atomic and subatomic scale.

Learning Objectives:

After going through this unit students will be able to:

- Understand the general feature of motion of a particle.
- Know how particles interact with the action of force.
- Explain the relationship between force and work done.

2.1. Kinematics in One and Two Dimensions

Self Diagnostic Test

- What does kinematics deals about?
- Can you state the kinematical quantities that describe the motion of objects?
- Can you distinguish instantaneous and average velocities? And accelerations?

A formal study of physics begins with kinematics. The word "kinematics" comes from a Greek word "kinesis" meaning motion, and is related to other English words such as "cinema" (movies) and "kinesiology" (the study of human motion). Kinematics is the branch of mechanics that describes the motion of objects without reference to the causes of motion (i.e., forces). Kinematics is concerned on analyzing kinematical quantities used to describe motion such as velocity, acceleration, displacement, time, and trajectory. Objects are in motion all around us. Planets moving around the sun, car moving along a road, blood flowing through veins, etc, are some examples of motion.

Objectives

At the end of this section you will be able to:

- Define kinematic terms such as position, displacement, velocity and acceleration
- Identify the difference between average and instantaneous velocity
- Identify the difference between average and instantaneous acceleration
- Drive kinematic equations for motions with constant acceleration
- Explain projectile motion and solve problems related to it
- Solve problems related to the concepts discussed in this chapter

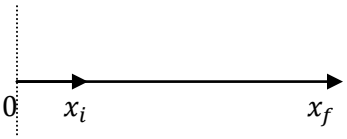
2.1.1. Displacement, velocity and Acceleration in 1D and 2D

Definition: Kinematical Quantities

Position: - The location of an object with respect to a chosen reference point.

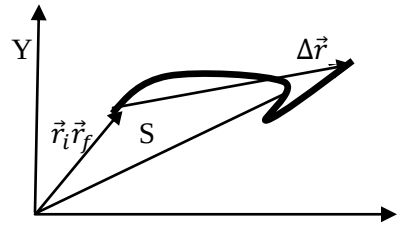
Displacement: - The change in position of an object with respect to a given reference frame.

For 1D (for one-dimensional motion)



$\Delta x = x_f - x_i$

For 2D



$\Delta\vec{r} = \vec{r}_f - \vec{r}_i$ ---------- (2.1.1)

Distance (S):- The length of the path followed by the object.

Average and Instantaneous Velocities:

Average Velocity ($\vec{v}_{av}$):-is the total displacement divided by the total time.

$\vec{v}_{av} = \frac{\Delta\vec{r}}{\Delta t} = \frac{\vec{r}_f - \vec{r}_i}{t_f - t_i}$ ---------- (2.1.2)

Average Speed: - is the total distance traveled by the object divided by the total elapsed time.

$$v_{av} = \frac{total\ distance(S)}{total\ time\ interval(\Delta t)}$$ ---------- (2.1.3)

Average speed and average velocity of an object do not provide the detail information of the entire motion. We may need to know the velocity or speed of the particle at a certain instant of time.

Instantaneous Velocity ($\vec{v}$): - is the limiting value of the ratio $\frac{\Delta\vec{r}}{\Delta t}$ as Δt approaches zero.

$$\vec{v} = \lim_{\Delta t \to 0} \frac{\Delta\vec{r}}{\Delta t}$$ ---------- (2.1.4)

The instantaneous speed:-It is the magnitude of the instantaneous velocity

Average and Instantaneous Accelerations:

If the velocity of a particle changes with time, then the particle is said to be accelerating.

Average acceleration: is the change in velocity ($\Delta\vec{v}$) of an object divided by the time interval during which that change occurs.

$$\vec{a}_{av} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$ ---------- (2.1.5)

Instantaneous acceleration: -The limit of average acceleration as Δt approaches zero.

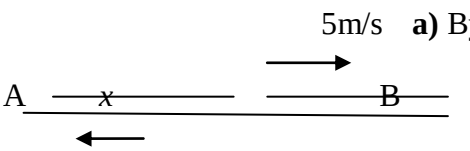
$$\vec{a}=\lim_{\Delta t\to 0}\frac{\Delta\vec{v}}{\Delta t} \text{ ---------- (2.1.6)}$$

Example

A person walks first at a constant speed of 5m/s along the straight line from point A to point B, and then back along the same line from B to A at a constant speed of 3m/s

a) What is his average speed over the entire trip
b) What is his average velocity over the entire trip

Solution



a) By definition, average speed is

$$v_{av}=\frac{total\ distance(S)}{total\ time\ interval(\Delta t)}$$

The total distance covered in the entire trip is $S_{AB}+S_{BA}=2x$

$$v_{av}=\frac{S_{tot}}{t_{tot}}=\frac{S_{AB}+S_{BA}}{t_{AB}+t_{BA}}$$

$$But, t_{AB}=\frac{x}{v_{AB}}=\frac{x}{5\text{m/s}}$$

$$t_{BA}=\frac{x}{v_{BA}}=\frac{x}{3\text{m/s}}$$

Therefore, $v_{av}=\frac{2x}{(\frac{x}{5\text{m/s}}+\frac{x}{3\text{m/s}})}=2x\left(\frac{15}{8x}\right)=\frac{15}{4}=3.75m/s$

b) Average velocity over the entire trip is zero, because for the entire trip

$$\vec{r}_f=\vec{r}_i\rightarrow\Delta\vec{r}=\vec{r}_f-\vec{r}_i=0$$

$$\vec{v}_{av}=\frac{\Delta\vec{r}}{\Delta t}=\frac{\vec{r}_f-\vec{r}_i}{t_f-t_i}=0$$

2.1.2. Motion with Constant Acceleration

For motion with constant acceleration,

- The velocity changes at the same rate throughout the motion.

- Average acceleration over any time interval is equal to the instantaneous acceleration at any instant of time.

$\vec{a}=\frac{\Delta\vec{v}}{\Delta t}=\frac{\vec{v}_f-\vec{v}_i}{t}$, assuming $t_i= 0$.

Rearranging this equation gives

$$\vec{v}_f = \vec{v}_i + \vec{a}t \quad \text{---------- (2.1.7)}$$

For motion with constant acceleration, average velocity can be written as:

$$\vec{v}_{av} = \frac{\vec{v}_f + \vec{v}_i}{2} \quad \text{---------- (2.1.8)}$$

By definition $\vec{v}_{av} = \frac{\Delta\vec{r}}{\Delta t}$ for $t_i=0$

$$\Delta\vec{r}=\vec{v}_{av}t$$

$$\vec{r}_f - \vec{r}_i = \frac{(\vec{v}_f + \vec{v}_i)t}{2} \text{but} \vec{v}_f = \vec{v}_i + \vec{a}t$$

$$\vec{r}_f - \vec{r}_i = \overrightarrow{v}_i t + \frac{1}{2}\vec{a}t^2 \quad \text{---------- (2.1.9)}$$

Again, $\Delta\vec{r}=\vec{v}_{av}t$ but $\vec{v}_{av} = \frac{\vec{v}_f + \vec{v}_i}{2}$ and t=$\frac{\vec{v}_f - \vec{v}_i}{a}$

$$\Delta\vec{r} = \frac{\overrightarrow{(v_f} + \vec{v}_i)}{2}\frac{\overrightarrow{(v_f} - \vec{v}_i)}{a}$$

$$v_f^2 = v_i^2+2a\Delta r \quad \text{---------- (2.1.10)}$$

For 2D motion $\vec{a} = a_x\hat{\imath} + a_y\hat{\jmath}$, $\vec{v}_f = v_{xf}\hat{\imath} + a_{yf}\hat{\jmath}$, $\vec{v}_i = v_{xi}\hat{\imath} + v_{yi}\hat{\jmath}$

$$\vec{v}_f = \vec{v}_i + \vec{a}t \rightarrow \begin{Bmatrix} v_{xf} = v_{xi} + a_x t \\ v_{yf} = v_{yi} + a_y t \end{Bmatrix}$$

$$\vec{r}_f - \vec{r}_i = \overrightarrow{v}_i t + \frac{1}{2}\vec{a}t^2 \rightarrow \begin{Bmatrix} \Delta x = v_{xi}t + \frac{1}{2}a_x t^2 \\ \Delta y = v_{yi}t + \frac{1}{2}a_y t^2 \end{Bmatrix}$$

Example 1

A track covers 40m in 8.5s while smoothly slowing down to a final speed of 2.8m/s. Find

a) Its original speed
b) b) its acceleration

Solution

We are given that *a)* $\Delta\vec{r}=\vec{v}_{av}t$

$S = 40m,\ t = 8.5\text{s}$ *and* $v_f = 2.8m/s$ *the magnitude of* $\vec{v}_{av}$ *is* $v_{av} = \frac{v_f+v_i}{2}$

the magnitude of $\Delta\vec{r}$ *is* $S = 40mS = \left(\frac{v_f+v_i}{2}\right)t \quad \rightarrow v_i = \frac{2S}{t} - v_f$

We are asked to find a)v_i *b)*$\vec{a}$ $v_i = \frac{2(40m)}{8.5s} - 2.8m/s$

$$= 9.4\frac{m}{s} - 2.8\frac{m}{s}$$

$$= 6.6m/s$$

$$b) \quad \vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{t}$$

The magnitude of the acceleration is

$$a = \frac{v_f - v_i}{t} = \frac{6.6m/s - 2.8m/s}{8.5s} = 0.447m/s^2$$

Example 2

A jet plane lands with a speed of 100m/s and slows down at a rate of 5m/s^2 as it comes to rest. a) What is the time interval needed by the jet to come to rest? b) Can this jet land on an airport where the runway is 0.8km long?

Solution

We are given that *a)* *the magnitude of the acceleration is* $v_i = \frac{100\text{m}}{\text{s}},\ a = -5\frac{\text{m}}{\text{s}^2}, v_f = 0$ $a = \frac{v_f - v_i}{t} \rightarrow t = \frac{v_f - v_i}{a}$

We are asked to find a) t *b)* S $t = \frac{0m/s - 100m/s}{-5m/\text{s}^2} = 20s$

b. To determine whether the jet can land on the 0.8km runway, we need to calculate the distance through which the jet moves as it comes to rest

$$S = \left(\frac{v_f + v_i}{2}\right)t$$

$$= \left(\frac{0m/s + 100m/s}{2}\right)20s$$

$$= 1000m = 1km$$

The jet can't land! because the runway(0.8km)is shorter than the distance the jet requires to come to rest(1km).

Activity:

1. At t=0s, a particle moving in the x-y plane with constant acceleration has a velocity of$\vec{v}_i = (3\hat{\imath}\text{-}2\hat{\jmath})$ m/s, and is at the origin. At t=3s, the particle's velocity is $\vec{v}_f = (9\hat{\imath}+7\hat{\jmath})$ m/s. Find (a)the acceleration of the particle (b) Its coordinates at t=3s

2.1.3. Free Fall Motion

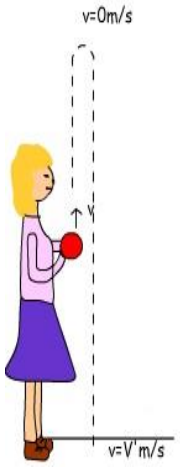
The motion of an object near the surface of the Earth under the only control of the force of gravity is called free fall. In the absence of air resistance, all objects fall with constant acceleration, g, toward the surface of the Earth. On the surface of the Earth, the generally accepted value is g = 9.8 m/s^2. The acceleration due to gravity varies with latitude, longitude and altitude on Earth's surface. And it is greater at the poles than at the equator and greater at sea level than a top mountain. There are also local variations that depend upon geophysics. The value of 9.8 m/s^2, with only two significant digits, is true for most places on the surface of the Earth up to altitudes of about 16 km.

Example

A girl throws a ball upwards, giving it an initial speed $u = 15\ m/s$. Neglect air resistance.
(a) How long does the ball take to return to the boy's hand? (b) What will be its velocity then?

Solution:

(a) We choose the positive y upward with its origin at the girl's hand, i.e. $y_i = 0$, see the Fig. below. Then, the ball's acceleration is negative (downward) during the ascending and descending motions, i.e. $a = -g = -9.8 m/s^2$.



When the ball returns to the girl's hand its position y is zero. Since $u=15m/s$, $y_i=0$, $y=0$, and $a=-g$, then we can find t from

$y - y_i = ut - \frac{1}{2} gt^2$ it follows:

$0 = (15m/s)\ t - \frac{1}{2}(9.8\ m/s^2) \times t^2$

$\Rightarrow t = 2 \times (15m/s)\ 9.8\ m/s^2 = 3.1s$

(b) We are given $u = 15m/s$, $y_i = 0$, $y = 0$, and $a = -g = -9.8\ m/s^2$. To find v, we use

(c) $v^2 = u^2 - 2g(y - y_i)$ it follows that:

$v^2 = u^2 - 0$

$\Rightarrow v = \pm u = \pm u = \pm 15\ m/s$

We should select the negative sign, because the ball is moving downward just before returning to the boy's hand, i.e. $v = -15\ m/s$.

2.1.4. Projectile Motion

Projectile is any object thrown obliquely into the space. The object which is given an initial velocity and afterwards follows a path determined by the gravitational force acting on it is called projectile and the motion is called projectile motion. A stone projected at an angle, a bomb released from an aero plane, a shot fired from a gun, a shot put or javelin thrown by the athlete are examples for the projectile. Consider a body projected from a point 'O' with velocity 'u'. The point 'o' is called point of projection and 'u' is called velocity of projection.

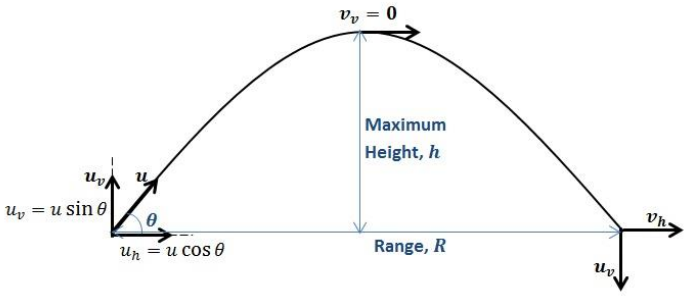


Figure 2.1: Motion of a projectile

Velocity of Projection (u): the velocity with which the body projected.

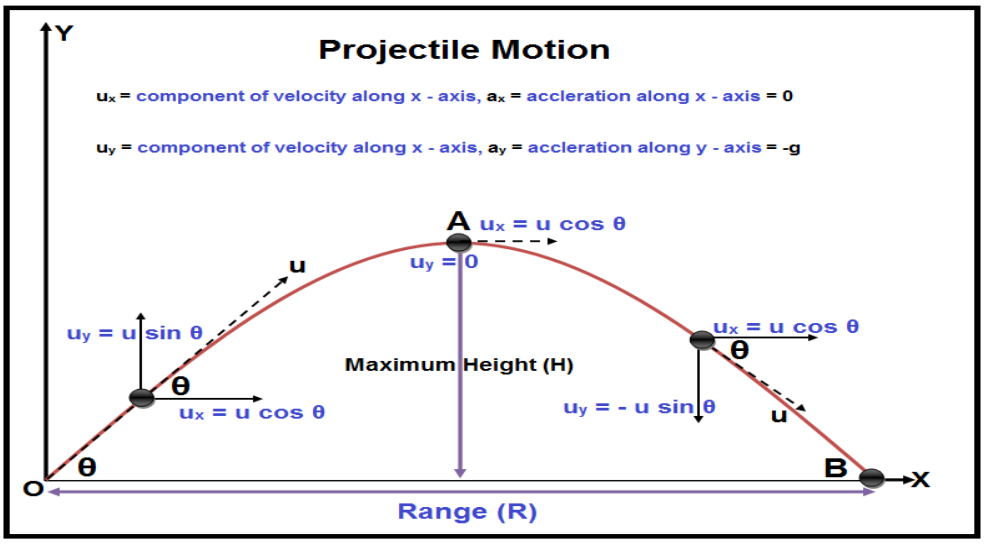
Angle of Projection (α): The angle between the direction of projection and the horizontal plane passing through the point of projection is called angle of projection.

Trajectory (OAB): The path described by the projectile from the point of projection to the point where the projectile reaches the horizontal plane passing through the point of projection is called trajectory. The trajectory of the projectile is a parabola.

Basic assumptions in projectile motion

- The free fall acceleration (g) is constant over the range of motion and it is directed downward.
- The effect of air resistance is negligible.

With the above two basic assumption the path of the projectile will be a down ward parabola.



For projectile motion $a_y = -g$

a_x=0 (Because there is no force acting horizontally)

The horizontal position of the projectile after some time t is:

$$\Delta x = u_x t + \frac{1}{2} a_x t^2$$

(x_i, y_i) = (0, 0) if the projectile is initially at the origin

$$x_f = u\cos\theta t + \frac{1}{2}(0)t^2$$

$$x_f = u\cos\theta t \quad \text{---------- (2.1.11)}$$

The vertical position of the projectile after some time t

$$\Delta y = u_y t + \frac{1}{2} a_y t^2$$

$$y_f = u\sin\theta t - \frac{1}{2} g t^2 \quad \text{---------- (2.1.12)}$$

The horizontal components of the velocity

$v_x = u_x + a_x t$ But a_x=0

$v_x = u_x = u\cos\theta$ ---------- (2.1.13)

The vertical components of the velocity

$$v_y = u_y + a_y t$$

$$v_y = usin\theta - gt \quad \text{---------- (2.1.14)}$$

Horizontal Range and Maximum Height

- When the projectile reaches the maximum height (the peak), $v_y = 0$

$$0 = usin\theta - gt$$

$t = \frac{usin\theta}{g}$(time to reach maximum height)

$$\text{At } y = h, \text{t} = \frac{usin\theta}{g} \rightarrow h = usin\theta(\frac{usin\theta}{g}) - \frac{1}{2}g(\frac{usin\theta}{g})^2$$

$$h = \frac{u^2 sin^2\theta}{2g} \quad \text{---------- (2.1.15)}$$

The Range(R) is the horizontal displacement of the projectile covered in a total time of flight.

$$t_{tot} = 2t, \text{ Where } t = \frac{usin\theta}{g}$$

$$t_{tot} = \frac{2usin\theta}{g} \quad \text{---------- (2.1.16)}$$

$$\text{When} x = R, t = t_{tot} = \frac{2usin\theta}{g}$$

$$R = (ucos\theta)(\frac{2usin\theta}{g}) \quad \text{But,} \quad 2sin\theta cos\theta = sin2\theta$$

$$R = \frac{u^2 sin2\theta}{g} \quad \text{---------- (2.1.17)}$$

The range (R) is maximum, when $sin2\theta = 1 \rightarrow 2\theta = 90^0 \rightarrow \theta = 45^0$

$$R_{max} = \frac{u^2}{g}$$

Example 1

A rocket is fired with an initial velocity of 100m/s at an angle of 55^0 above the horizontal. It explodes on the mountain side 12s after its firing. What is the x-and y- coordinates of the rocket relative to its firing point?

Solution:

We are given that

$u = 100m/s, \ \theta = 55^0, t = 12s$

We are asked to find the horizontal position(x)

$$x(t) = ucos\theta t$$

$$= (100m/s)cos55^0(12s)$$

$$x = 688.3m$$

and the vertical position (y) of the rocket $y(t) = usin\theta t - \frac{1}{2}gt^2$

$=(100m/s)(sin55^0)(12s) - \frac{1}{2}(9.8m/s^2)(12s)^2$

$= 983m - 706m$

y $= 277m$

Example 2

A plane drops a package to a party of explorer. If the plane is travelling horizontally at 40m/s and is 100m above the ground, where does the package strike the ground relative to the point at which it is released?

Solution

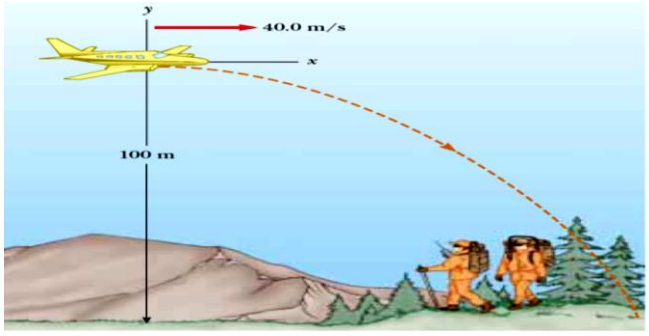
- *We are given that*

$$u = u_x = 40m/s,$$

Since the vertical displacement is below the reference point $y = -100m$

- *We are asked to find the horizontal displacement (x)*

  $x(t) = ucos\theta t$ *but in this case* $u = u_x$ *and* $\theta = 0$



$x(t) = v_x t$ *(1)*

We can find t from equation for the vertical displacement

$$y(t) = usin\theta t - \frac{1}{2}gt^2$$

But $\theta = 0 \rightarrow sin\theta = 0$

$$y(t) = 0 - \frac{1}{2}gt^2$$

$$-100m = -\frac{1}{2}(\frac{9.8m}{s^2})t^2$$

$$t = 4.52s$$

Substituting this value of t in (1)

$$x(t = 4.52s) = (40m/s)(4.52)$$

$$= 181m$$

Activities

1. A ball is thrown with an initial velocity of $\vec{u} = (10\hat{\imath}+15\hat{\jmath})$ m/s. When it reaches the top of its trajectory, neglecting air resistance, what is its a) velocity? b) Acceleration?
2. An astronaut on a strange planet can jump a maximum horizontal distance of 15m if his initial speed is 3m/s. What is the free fall acceleration on the planet?

2.2. Particle Dynamics and Planetary Motion

Self Diagnostic Test

- What do you think about the cause for the change in the state of motion of an object?
- What makes planets to revolve around the sun keeping their trajectory?

In the previous section, we have described motion in terms of displacement, velocity, and acceleration without considering what might cause that motion. Here we investigate what causes changes in the state of motion. What cause particles to remain at rest or accelerate? It is because of the mass of the object and forces acting on it. Knowledge of Newton's laws and the ability to apply them to various situations will allow us to explain much of the motion we observe in the world around us. They are also very important for analyzing things (like bridges) that don't move much (a subject called Statics that's important in some Engineering programs). Newtonian dynamics was initially developed in order to account for the motion of the Planets around the Sun, which we discuss the problem in this part of the unit while discussing Kepler's laws of planetary motion.

Objectives

At the end of this section, you will be able to:

- State the three Newton's laws of motion
- Explain the behavior of action-reaction forces
- Describe the nature and types of friction forces
- Apply Newton's laws of motion in solving some problems
- Discuss how an object accelerates in uniform circular motion.
- State Kepler's laws of planetary motion

Force: any interaction that changes the motion an object. A force moves or tends to move, stops or tends to stop the motion of the object. The force can also change the direction of motion of an object. It can also change the shape or size of a body on which it acts.

Net force: is defined as the vector sum of all the forces acting on the object. The object accelerates only if the net force ($\vec{F}_{net}$) acting on it is not equal to zero.

2.2.1. The Concept of Force as A Measure of Interaction

In physics, any of the four basic forces gravitational, electromagnetic, strong nuclear and weak forces govern how particles interact. All other forces of nature can be traced to these fundamental interactions. The fundamental interactions are characterized on the basis of the following four criteria:

- the types of particles that experience the force,
- the relative strength of the force,
- the range over which the force is effective, and
- the nature of the particles that mediate the force.

2.2.2. Type of Forces

Self diagnostic test

List the types of forces you know and try to classify them as contact forces and field forces.

Forces are usually categorized as *contact* and *non-contact*.

Contact Force

It is a type of force that requires bodily contact with another object. And it is further divided into the following.

A. Muscular Forces

Muscles function to produce a resulting force which is known as 'muscular force'. Muscular force exists only when it is in contact with an object. We apply muscular force during the basic day to day work of our life such as breathing, digestion, lifting a bucket, pulling or pushing some object. Muscular force comes in handy to simply our work.

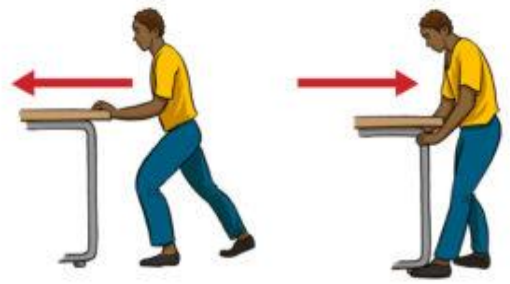
B. Frictional Forces

When an object changes its state of motion, 'frictional force" acts upon. It can be defined as the resisting force that exists when an object is moved or tries to move on a surface. The frictional force acts as a point of contact between two surfaces that is it arises due to contact between two surfaces. Examples; lighting a matchstick or stopping a moving ball come under frictional force.

C. Normal Force

When a book is lying on the table, even though it seems that it's stationary, it's not. An opposing force is still acting on the book wherein the force from gravity is pulling it towards the Earth. This force is the 'normal force'. They always act perpendicular to the surface.

1. Applied Force

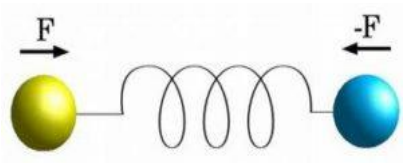


When you push a table across the room, you apply a force that acts when it comes in contact with another object. This is 'applied force'; i.e. a force that is applied to a person or object.

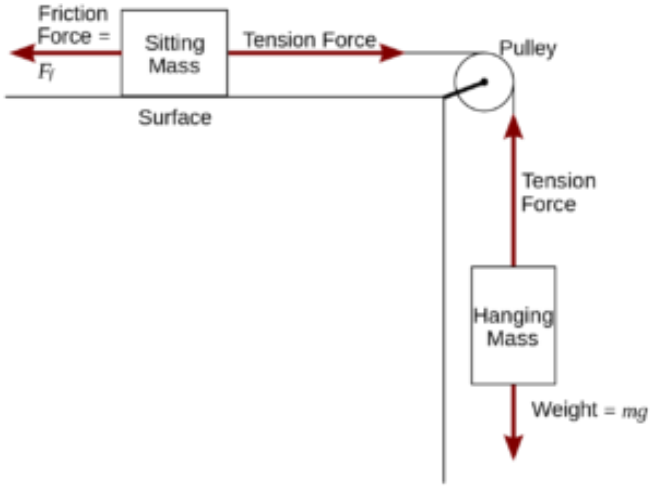
2. Tension Force

Tension is the force applied by a fully stretched cable or wire anchored on to an object. This causes a 'tension force' that pulls equally in both directions and exerts equal pressure.

3. Spring Force



Force exerted by a compressed or stretched spring is 'spring force'. The force created could be a push or pull depending on how the spring is attached.



4. Air Resisting Force

Air resisting forces are types of forces wherein objects experience a frictional force when moving through the air. These forces are resistive in nature.

Non-Contact Force

It is a type of force that does not require a physical contact with the other object. It is further divided into the following types of forces:

5. **Gravitational Force**

Gravitational force is an attractive force that can be defined by Newton's law of gravity which states that 'gravitational forces between two bodies are directly proportional to the product of their masses and inversely proportional to the square of the distance between them' (more on this later). It is a force exerted by large bodies such as planets and stars. E**xample**: water droplets falling down

6. **Magnetic Force**

The types of forces exerted by a magnet on magnetic objects are 'magnetic forces'. They exist without any contact between two objects.

7. **Electrostatic Force**

The types of forces exerted by all electrically charged bodies on another charged bodies in the universe are 'electrostatic forces'. These forces can be both attractive and repulsive in nature based on the type of charge carried by the bodies.

2.2.3. Newton's Laws of Motion and Applications

Laws of motions are formulated for the first time by English physicist Sir Isaac Newton in 1687. Newton developed the three laws of motion in order to explain why the orbits of the planets are ellipses rather than circles, at which he succeeded. Newton's laws continue to give an accurate account of nature, except for very small bodies such as electrons or for bodies moving close to the speed of light.

Newton's First law of Motion:

"Everybody continues in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by forces impressed upon it."

This is sometimes called the *Law of Inertia.* Essentially, it makes the following two points:

- An object that is not in motion will not move until a force acting upon it.
- An object in constant motion will not change its velocity until a force acts upon it.

Another way of stating Newton's First Law of motion: *A body that is acted on by no net force moves at a constant velocity (which may be zero) and zero acceleration*. So with no net force, the object just keeps doing what it is doing. It is important to note the words *net force*. This means the vector sum of total forces acting upon the object must add up to zero. An object sitting on a floor has a gravitational force pulling it downward, but there is also a *normal force* pushing upward from the floor, so the net force is zero. Therefore, it doesn't move.

Newton's Second law of Motion:

The acceleration acquired by a point particle is directly proportional to the net force acting on the particle and inversely proportional to its mass and the acceleration is always in the direction of the net force.

Mathematically, $\sum \mathbf{F} = m\boldsymbol{a}$ ……(2.2.1)

Where $\sum \boldsymbol{F}$ is the net force acting on the particle, m is the mass of the particle and $\boldsymbol{a}$ is the acceleration of the particle. You'll note that when the net forces on an object sum up to zero, we achieve the state defined in Newton's First Law: the net acceleration must be zero. We know this because all objects have mass (in classical mechanics, at least). If the object is already moving, it will continue to move at a constant velocity, but that velocity will not change until a net force is introduced. Obviously, an object at rest will not move at all without a net force.

Example 1

A box with a mass of 40 kg sits at rest on a frictionless tile floor. With your foot, you apply a 20 N force in a horizontal direction. What is the acceleration of the box?

Solution:

The object is at rest, so there is no net force except for the force your foot is applying. Friction is eliminated. Also, there's only one direction of force to worry about. So this problem is very straightforward.

We begin the problem by defining the coordinate system. The mathematics is similarly straightforward:

$$\boldsymbol{F} = m\boldsymbol{a}$$

$$\boldsymbol{F} / m = \boldsymbol{a}$$

$$20 \text{ N} / 40 \text{ kg} = \boldsymbol{a} = 0.5 \text{ m} / \text{s}^2$$

The problems based on this law are literally endless, using the formula to determine any of the three values when you are given the other two. As systems become more complex, you will learn to apply frictional forces, gravity, electromagnetic forces, and other applicable forces to the same basic formulas.

Example 2

A 3kg object undergoes an acceleration given by $\vec{a} = (2\hat{\imath} + 5\hat{\jmath})m/s^2$. Find the magnitude of the resultant force.

Solution

We are given that

$m = 3kg, \vec{a} = (2\hat{\imath} + 5\hat{\jmath})\dfrac{m}{s^2}$

We are asked to find the magnitude of $\vec{F}$

$$\vec{F} = m\vec{a}$$

$$= (3kg)(2\hat{\imath} + 5\hat{\jmath})m/s^2$$

$$\vec{F} = (6\hat{\imath} + 15\hat{\jmath})N$$

The magnitude of the force is

$$\left|\vec{F}\right| = \sqrt{6^2 + 15^2} = 16.15N$$

Newton's Third law of Motion

States that "For every action there is always an equal and opposite reaction."

To understand this law, consider two bodies *A* and *B* that are interacting and let $\boldsymbol{F_{BA}}$ is the force applied on body *A* by body *B*, and $\boldsymbol{F_{AB}}$ is the force applied on body *B* by body *A*. These forces will be equal in magnitude and opposite in direction. In mathematical terms, it is expressed as:

$$\boldsymbol{F_{BA}} = -\boldsymbol{F_{AB}} \quad \textbf{or } \boldsymbol{F_{AB}} + \boldsymbol{F_{BA}} = 0$$

This is not the same thing as having a net force is zero, however. Action and reaction forces are not treated the same as the forces acting on stationary object, normal force and weight of the object.

Note that:

- Action and reaction forces are always exist in pair
- A single isolated force cannot exist
- Action and reaction forces act on different objects

Activities

1. Find the force needed to accelerate a mass of 40kg from velocity $\vec{v}_i = (4\hat{\imath} - 5\hat{\jmath} + 3\hat{k})m/s$ to $\vec{v}_f = (8\hat{\imath} + 3\hat{\jmath} - 5\hat{k})m/s$ in 10s
2. If a man weighs 900N on earth, what is his weight on Jupiter where the acceleration due to gravity is $25.9 m/s^2$?

Forces of Friction

Self Diagnostic Test

- What makes you walk on the surface of the Earth without slipping?
- How can you express your interaction with the surrounding air while you are walking or running?

Frictional force refers to the force generated by two surfaces that are in contact and either at rest or slide against each other. These forces are mainly affected by the surface texture and amount of force impelling them together.

The angle and position of the object affect the amount of frictional force.

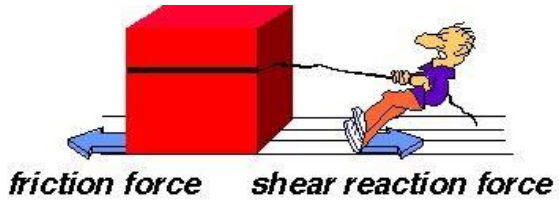
- *If an object is placed on a horizontal surface against another object, then the frictional force will be equal to the weight of the object.*
- *If an object is pushed against the surface, then the frictional force will be increased and becomes more than the weight of the object.*

Generally friction force is always proportional to the normal force between the two interacting surfaces. Mathematically

$$F_{frict} \propto F_{norm}$$

$$\boldsymbol{F_f} = \mu F_N \text{.....(2.2.2)}$$

Where the proportionality constant $\boldsymbol{\mu}$ is the coefficient of friction



Forces of friction are very important in our everyday lives. They allow us to walk or run and are necessary for the motion of wheeled vehicles. Therefore, friction forces are categorized in the following manner:

a) **Static friction**: exists between two stationary objects in contact to each other. Mathematically static friction is written as

$$f_s = f_{s,max} = \mu_s N \text{----------} \quad (2.2.3)$$

$$Where\ \mu_s\ is\ the\ coefficient\ of\ static\ friction$$

b) **Kinetic friction**: arises when the object is in motion on the surface. The magnitude of the force of kinetic friction acting between two surfaces is

$$f_k = \mu_k N \text{----------} \quad (2.2.4)$$

Where μ_k is called the coefficient of kinetic friction.

- The values of μ_k and μ_s depend on the nature of the surfaces, but μ_k is generally less than μ_s (which implies that $f_k < f_s$). Typical values range from around 0.03 to 1.0.
- The direction of the friction force on an object is parallel to the surface with which the object is in contact and opposite to the actual motion (kinetic friction) or the impending motion (static friction) of the object relative to the surface.
- The coefficients of friction are nearly independent of the area of contact between the surfaces.

Example

A 25.0-kg block is initially at rest on a horizontal surface. A horizontal force of 75.0 N is required to set the block in motion. After it is in motion, a horizontal force of 60.0 N is required to keep the block moving with constant speed. Find the coefficients of static and kinetic friction from this information.

Solution

We are given that $f_s=\mu_s N$ *but* $N = mg$

$m = 25kg, f_s = 75N,\ f_k = 60N$ $\mu_s = \frac{f_s}{mg} = \frac{75N}{(25kg)(9.8m/s^2)}$

We are asked to find $\mu_s \& \mu_k$ $\mu_s = 0.31$

$f_k=\mu_k N$ *but* $N = mg$

$$\mu_k = \frac{f_k}{mg} = \frac{60N}{(25kg)(9.8m/s^2)}$$

$$\mu_s = 0.245$$

Application of Newton's Laws of Motion

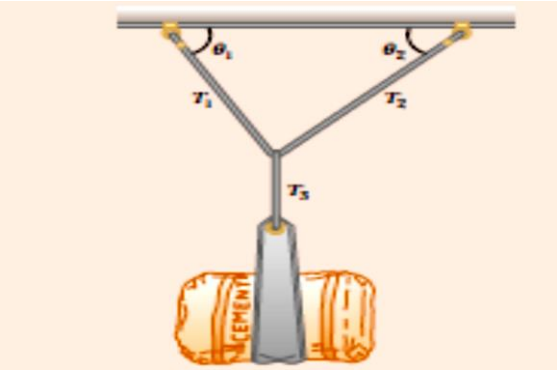
In this section we apply Newton's laws to objects that are either in equilibrium ($\vec{a}$= 0) or accelerating along a straight line under the action of constant external forces. Remember that when we apply Newton's laws to an object, we are interested only in external forces that act on the object. We assume that the objects can be modeled as particles so that we need not worry about rotational motion. We usually neglect the mass of any ropes, strings, or cables involved.

The following procedure is recommended when dealing with problems involving Newton's laws:

1. Draw a sketch of the situation.
2. Consider only one object (at a time), and draw a free-body diagram for that body, showing all the forces acting on that body. Do not show any forces that the body exerts on other bodies. If several bodies are involved, draw a free-body diagram for each body separately, showing all the forces acting on that body.
3. Newton's second law involves vectors, and it is usually important to resolve vectors into components. Choose an x and y axis in a way that simplifies the calculation.
4. For each body, Newton's second law can be applied to the x and y components separately. That is the x component of the net force on that body will be related to the x component of that body's acceleration: $F_x=ma_x$, and similarly for the y direction.
5. Solve the equation or equations for the unknown(s).

Example 1

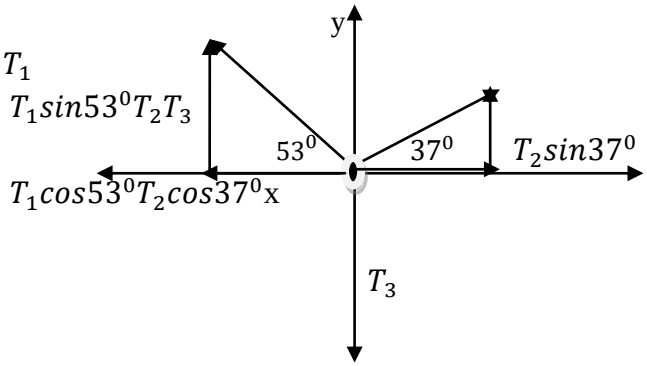
A bag of cement of weight 300 N hangs from three ropes as shown in the figure below. Two of the ropes make angles of $\theta_1 = 53.0°$ and $\theta_2 = 37.0°$ with the horizontal. If the system is in equilibrium, find the tensions T_1, T_2, and T_3 in the ropes.



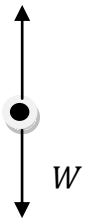
Solution

We can draw two free body diagrams for the problem as follows

a)



b)



Since the system is in equilibrium, $\sum \vec{F} = 0 \rightarrow \begin{cases} \sum F_x = 0 \\ \sum F_y = 0 \end{cases}$

From free body diagram (a) $\sum F_x = T_2 cos37^0 - T_1 cos53^0 = 0$

$$0.8T_2 = 0.6\,T_1 \text{(a)}$$

$$\sum F_y = T_1 sin53^0 + T_2 sin37^0 - T_3 = 0$$

$$0.8\,T_1 + 0.6\,T_2 = T_3 \text{(b)}$$

From free body diagram (b) $\sum F_y = T_3 - W = 0 \rightarrow \boldsymbol{T_3 = W = 300N}$(c)

Substituting(c) in (b) $0.8\,T_1 + 0.6\,T_2 = 300N$ (d)

But $0.8T_2 = 0.6\,T_1 \rightarrow T_2 = \frac{0.6\,T_1}{0.8} = 0.75T_1$

Substituting for T_2in (d) Gives

$0.8\,T_1 + 0.6(0.75T_1) = 300N$

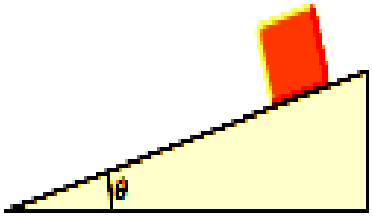
$$\boldsymbol{T_1 = 240N}$$

$$T_2 = 0.75T_1 = 0.75(240N)$$

$$\boldsymbol{T_2 = 180N}$$

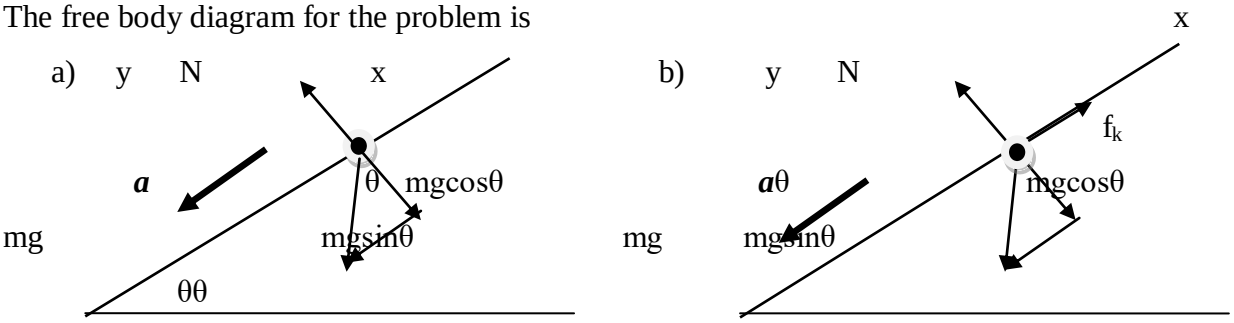
Example 2

A block of mass m slides down an inclined plane as shown in the figure below. Find the expression for the acceleration of the block. (a)If the inclined plane is frictionless (b)If the inclined plane has coefficient of kinetic friction μ_k



Solution

The free body diagram for the problem is



a) If the inclined plane is frictionless, the only forces acting on the block are the gravitational force (mg) downward and the normal force (N).

Resolving mg into parallel and perpendicular to the direction of motion of motion

Considering parallel component to be along the $x-$ *axis*

$$\sum F_x = mgsin\theta = ma$$

$$a = gsin\theta$$

b) If the inclined plane has coefficient of kinetic friction μ_k, the forces acting on the block are shown in free body diagram (b)

from the parallel component to the direction of motion

$$\sum F_x = mgsin\theta - f_k = ma$$

$$mgsin\theta - \mu_k N = ma$$

from the perpendicular component to the direction of motion

$$N - mgcos\theta = 0 \ \rightarrow N = mgcos\theta$$

$$mgsin\theta - \mu_k mgcos\theta = ma$$

$$a = g(sin\theta - \mu_k cos\theta)$$

2.2.4. Uniform Circular Motion

Self Diagnostic Test

Do you know that objects moving with constant speed can have acceleration? When does this occur?

Uniform Circular Motion is motion of objects in a circular path with a constant speed. Objects moving in a circular path with a constant speed can have acceleration.

$$\vec{a}=\frac{\Delta\vec{v}}{\Delta t}$$

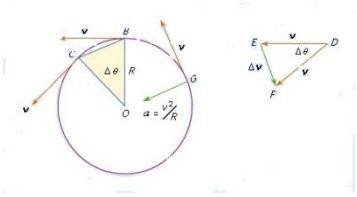
There are two ways in which the acceleration can occur due to:

- change in magnitude of the velocity
- change in direction of the velocity

For objects moving in a circular path with a constant speed, acceleration arises because of the change in direction of the velocity.

Hence, in case of uniform circular motion:

- Velocity is always tangent to the circular path and perpendicular to the radius of the circular path.
- Acceleration is always perpendicular to the circular path, and points towards the center of the circle. Such acceleration is called the **centripetal acceleration**



$$|\vec{r}_i| = |\vec{r}_f| = r$$

The angle $\Delta\theta$ in figure (a) and (b) are the same

By SAS similarity $\frac{|\Delta\vec{v}|}{|\Delta\vec{r}|} = \frac{v}{r} \rightarrow |\Delta\vec{v}| = \frac{(|\Delta\vec{r}|)v}{r}$

$$|\vec{a}|=\frac{|\Delta\vec{v}|}{\Delta t} \rightarrow \left(\frac{|\Delta\vec{r}|}{\Delta t}\right)\left(\frac{v}{r}\right) = \frac{v^2}{r}$$

$$a_c = \frac{v^2}{r}$$ (Centripetal acceleration) ---------- (2.3.1)

Period (T):- Time required for one complete revolution

For a particle moving in a circle of radius r with a constant speed

$$v = \frac{2\pi r}{T} \rightarrow T = \frac{2\pi r}{v}$$ ---------- (2.3.2)

Activity

An athlete rotates a discus along a circular path of radius 1.06m.If the maximum speed of the disc us is 20m/s, determine the magnitude of the maximum centripetal acceleration.

2.2.5. Newton's Law of Universal Gravitation

Self Diagnostic Test

→ What do you think when the Earth is always revolving around the Sun without slipping and leaving its line of revolution?

Gravity is the weakest of the four basic forces found in nature, and in some ways the least understood. Newton was the first scientist to precisely define the gravitational force, and to show that it could explain both falling bodies and astronomical motions. But Newton was not the first person to suspect that the same force caused both our weight and the motion of planets. His forerunner Galileo Galilei had contended that falling bodies and planetary motions had the same cause. Some of Newton's contemporaries, such as Robert Hooke, Christopher Wren, and Edmund Halley, had also made some progress toward understanding gravitation. But Newton was the first to propose an exact mathematical form and to use that form to show that the motion of heavenly bodies should be conic sections; circles, ellipses, parabolas, and hyperbolas. This theoretical prediction was a major triumph, it had been known for some time that moons, planets, and comets follow such paths, but no one had been able to propose a mechanism that caused them to follow these paths and not others.

The gravitational force is always attractive, and it depends only on the masses involved and the distance between them. **Newton's universal law of gravitation** states that every particle in the universe attracts every other particle with a force along a line joining them. The force is directly

proportional to the product of their masses and inversely proportional to the square of the distance between them.

Gravitational attraction is along a line joining the centers of mass of these two bodies. The magnitude of the force is the same on each, consistent with Newton's third law.

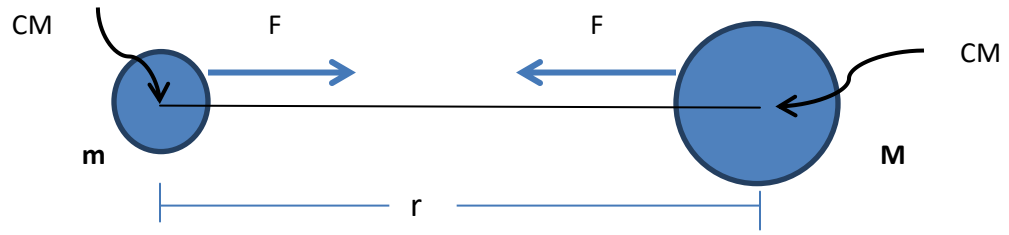


Figure 2.2: Interaction of two objects with gravitational force

$$\vec{F} = \frac{GmM}{r^2}\hat{r} \quad \text{.....(2.3.4)}$$

Here, r is the distance between the centers of mass of the bodies, *G* is the gravitational constant, whose value found by experiment is $G = 6.674 \times 10^{-11}\ Nm^2/kg^2$ in SI units.

The small magnitude of the gravitational force is consistent with everyday experience. We are unaware that even large objects like mountains exert gravitational forces on us. In fact, our body weight is the force of attraction of the *entire Earth* on us with a mass of $6 \times 10^{24} kg$.

Recall that the acceleration due to gravity g is about $9.8 m/s^2$ on Earth. We can now determine why this is so. The weight of an object *mg* is the gravitational force between it and Earth. Substituting *mg* for F in Newton's universal law of gravitation gives

$$mg = \frac{GmM.}{r^2}$$

Where, ***m*** is the mass of the object, ***M*** is the mass of Earth, and ***r*** is the distance to the center of Earth (the distance between the centers of mass of the object and Earth). The mass ***m*** of the object cancels, leaving an equation for ***g***:

$$g = \frac{GM.}{r^2} \quad \text{..... (2.3.5)}$$

Substituting known values for Earth's mass and radius (to three significant figures),

$$g = (6.67 \times 10 - 11\ \frac{\mathrm{Nm^2}}{\mathrm{kg^2}})(\frac{5.98x10^{24}kg^2}{6.38x10^6 m})$$

and we obtain a value for the acceleration of a falling body:

$$g = 9.8\frac{m}{s^2}$$

The distance between the centers of mass of Earth and an object on its surface is very nearly the same as the radius of Earth, because Earth is so much larger than the object.

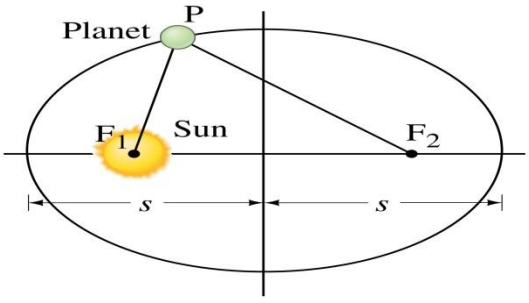
This is the expected value *and is independent of the body's mass*. Newton's law of gravitation takes Galileo's observation that all masses fall with the same acceleration a step further, explaining the observation in terms of a force that causes objects to fall, in fact, in terms of a universally existing force of attraction between masses.

2.2.6. Kepler's Laws, Satellites Motion and Weightlessness

The basic laws of planetary motion were established by Johannes Kepler (1571-1630) based on the analysis of astronomical observations of Tycho Brahe (1546−1601). In 1609, Kepler formulated the first two laws. The third law was discovered in 1619. Later, in the late 17th century, Isaac Newton proved mathematically that all three laws of Kepler are a consequence of the law of universal gravitation.

Kepler's First Law (Law of Orbits)

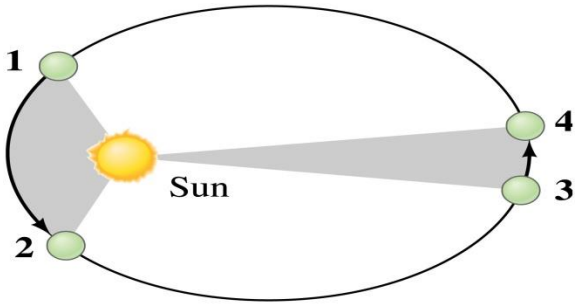
States that the orbit of each planet in the solar system is an ellipse, the Sun will be on one focus. The points F_1 and F_2represented in figure are known as the **foci** of the ellipse. The closer together that these points are, the more closely that the ellipse resembles the shape of a circle. In fact, a circle is the special case of an ellipse in which the two foci are at the same location. Kepler's first law is rather simple - all planets orbit the sun in a path that resembles an ellipse, with the sun being located at one of the foci of that ellipse.



Kepler's Second Law (The Law of Areas)

States that "the radius vector connecting the centers of the Sun and the Planet sweepsout equal areas in equal intervals of time."The Figure below shows the two sectors of the ellipse having equal areas corresponding to the same time intervals. The second

law describes the speed (which is constantly changing) at which any given planet will move while orbiting the sun. A planet moves fastest when it is closest to the sun and slowest when it is furthest from the sun. Yet, if an imaginary line were drawn from the center of the planet to the center of the sun, that line would sweep out the same area in equal periods of time.



Kepler's Third Law (The Law of Harmony)

States that *"the square of the orbital period of a planet is proportional to the cube of the average distance between the centers of the planet and the sun."*

Unlike Kepler's first and second laws that describe the motion characteristics of a single planet, the third law makes a comparison between the motion characteristics of different planets. The comparison being made is that the ratio of the squares of the periods to the cubes of their average distances from the sun is the same for every one of the planets. As an illustration, consider the orbital period and average distance from sun (orbital radius) for Earth and mars as given in the table below.

Planet	**Period (s)**	**Average Distance (m)**	**T^2/R^3 (s^2/m^3)**
Earth	3.156×10^7 s	1.4957×10^{11}	2.977×10^{-19}
Mars	5.93×10^7 s	2.278×10^{11}	2.975×10^{-19}

Observe that the T^2/R^3 ratio is the same for Earth as it is for mars. In fact, if the same T^2/R^3 ratio is computed for the other planets, it can be found that this ratio is nearly the same value for all the planets (see table below). Amazingly, every planet has the same T^2/R^3 ratio.

Planet	**Period**	**Average**	**T^2/R^3**

	(yr)	Distance (au)	(yr^2/au^3)
Mercury	0.241	0.39	0.98
Venus	.615	0.72	1.01
Earth	1.00	1.00	1.00
Mars	1.88	1.52	1.01
Jupiter	11.8	5.20	0.99
Saturn	29.5	9.54	1.00
Uranus	84.0	19.18	1.00
Neptune	165	30.06	1.00
Pluto	248	39.44	1.00

(**NOTE**: The average distance value is given in astronomical units where 1 a.u. is equal to the distance from the earth to the sun - 1.4957×10^{11} m. The orbital period is given in units of earth-years where 1 earth year is the time required for the earth to orbit the sun - 3.156×10^{7} seconds.)

Activity:

- In what frame(s) of reference are Kepler's laws valid? Are Kepler's laws purely descriptive, or do they contain causal information?

Satellite motion and Weightlessness

Self Diagnostic Test

Astronauts on the orbiting space station are *weightless* because:

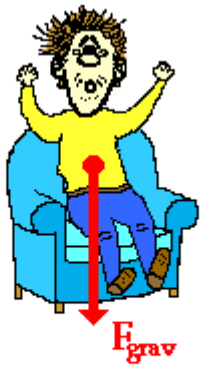
- There is no gravity in space and they do not weigh anything.
- Space is a vacuum and there is no gravity in a vacuum.
- Space is a vacuum and there is no air resistance in a vacuum.
- The astronauts are far from Earth's surface at a location where gravitation has a minimal effect.

Astronauts who are orbiting the Earth often experience sensations of weightlessness. These sensations experienced by orbiting astronauts are the same sensations experienced by anyone who has been temporarily suspended above the seat on an amusement park ride. Not only are the

sensations the same (for astronauts and roller coaster riders), but the causes of those sensations of weightlessness are also the same. Unfortunately however, many people have difficulty understanding the causes of weightlessness.

The cause of weightlessness is quite simple to understand. However, the stubbornness of one's preconceptions on the topic often stands in the way of one's ability to understand. What was your answer for the self-diagnostic test given above? Read the statements given below and use your knowledge of contact and non-contact force to understand well and find the answer. (**MIND YOU**: none of them are answers!)

Weightlessness is simply a sensation experienced by an individual when there are no external objects touching one's body and exerting a push or pull upon it. Weightless sensations exist when all contact forces are removed. These sensations are common to any situation in which you are momentarily (or perpetually) in a state of free fall. When in free fall, the only force acting upon your body is the force of gravity, a non-contact force. Since the force of gravity cannot be felt without any other opposing forces, you would have no sensation of it. You would feel weightless when in a state of free fall.



A person in free fall does not experience any contact force and thus feels weightless.

2.3. Work, Energy and Linear Momentum

On a typical day, you probably wake up, get dressed, eat breakfast, and head off to work. After you spend all day at your job, you go home, eat dinner, walk the dog, maybe watch some TV, and then go to bed. In this sense, work can be just about anything - construction, typing on a keyboard, driving a bus, teaching a class, cooking food, treating patients, and so much more. But in physics, work is more specific. This is the displacement of an object due to force. How much work is done depends on the distance the object is moved.

Work can be defined as transfer of energy due to an applied force. In physics we say that work is done on an object when energy is transferred to that object. If one object transfers (gives) energy to a second object, then the first object does work on the second object. The energy of a moving object is called kinetic energy.

The work done on an object by conservative force over any displacement is a function only of the difference in the positions of the end-points of the displacement. This property allows us to define a different kind of energy for the system than its kinetic energy, which is called potential energy. Potential energy is a state of the system, a way of storing energy as of virtue of its configuration or motion, while work done in most cases is a way of changing this energy from one body to another. When only conservative forces act within an isolated system, the kinetic energy gained (or lost) by the system as its members change their relative positions is balanced by an equal loss (or gain) in potential energy. This balancing of the two forms of energy is known as the *principle of conservation of mechanical energy*.

Objectives

At the end of this section, you will be able to:

- Define work, kinetic energy and potential energy
- Calculate the work done by a constant force
- Derive work-kinetic energy theorem and apply in solving related problems
- State the principle of conservation of mechanical energy
- Solve problems related to the topics discussed in this section.

2.3.1. Work and Energy

Self Diagnostic Test

→ Can we use work and energy interchangeably?
→ Can work be expressed in terms of the kinetic energy of an object and vice versa?

The terms work and energy are quite familiar to us and we use them in various contexts. In physics, work is done when a force acts on an object that undergoes a displacement from one position to another. Forces can vary as a function of position, and displacements can be along various paths between two points. If no displacement takes place, no work is said to be done. Therefore for work to be done on an object, three essential conditions should be satisfied:

- Force must be exerted on the object
- The force must cause a motion or displacement

- The force should have a component along the line of displacement

If a particle subjected to a constant force $\vec{F}$ undergoes a certain displacement, $\Delta\vec{r}$, the work done W by the force is given by:

$$W = \vec{F}.\Delta\vec{r} = |\vec{F}||\Delta\vec{r}|\cos\theta \quad \text{---------- (2.3.1)}$$

Where θ is the angle between $\vec{F}$ and $\Delta\vec{r}$.

Work is a scalar quantity and its SI unit is Joule (J). Where,

$$1J = 1N.1m$$

The sign of work depends on the direction of $\overrightarrow{F}$ relative to $\Delta\vec{r}$. Hence, the work done by the applied force is positive when the projection of $\overrightarrow{F}$ onto $\Delta\vec{r}$ is in the same direction as $\Delta\vec{r}$.

Consider the Mass-spring system where the force applied varies with position constantly. A block on a horizontal, frictionless surface is connected to a spring as shown in the figure below.
If the spring is either stretched or compressed a small distance from its un-stretched (equilibrium) configuration, it exerts on the block a force that can be expressed as:

$$F_s = -kx \text{ (Hook's Law)} \quad \text{---------- (2.3.2)}$$

- x is the position of the block relative to its equilibrium (x = 0) position
- k is a positive constant called the force constant or the spring constant of the spring.
- F_s is called restoring force

The negative sign in the equation signifies that the force exerted by the spring is always directed *opposite* to the displacement from equilibrium.

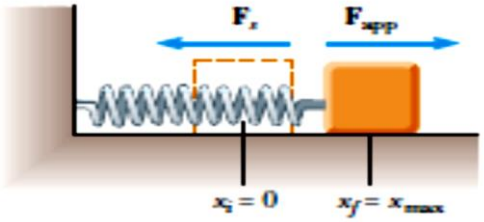


Figure 2.3: Mass-spring system (left), graphical representation of the motion of mass-spring system (right)

Work done by the restoring force if the block undergoes an arbitrary displacement from x_i to x_f is the area enclosed by the above graph.

$$Area = W = \frac{1}{2}(F_s \, x \, \Delta X), \qquad but \qquad F_s = -k\Delta X$$

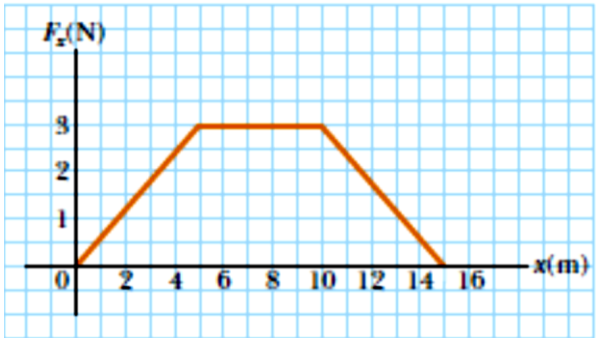
$$W = \frac{1}{2}kx_i^2 - \frac{1}{2}kx_f^2 \text{---------- (2.3.3)}$$

If the work is done by the applied force

$W_{F_{app}} = \frac{1}{2}kx_f^2 - \frac{1}{2}kx_i^2$ because $F_{app} = k\Delta X$

Example

A particle is subject to a force F_x that varies with position as in figure below. What is the total work done by the force over the distance, x= 0 to x = 15.0 m?



Solution

The total work done is equal to the area under the F_x versus x curve

$$W = (F_x)(\Delta x) = \Delta A$$

$$= \frac{1}{2}(5)(3) + (5)(3) + \frac{1}{2}(5)(3)$$

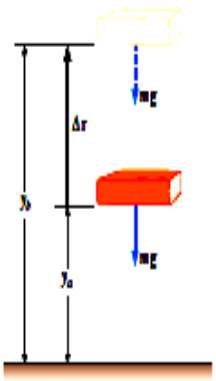
$$W = 30J$$

Energy is the crown for physics. It is found in every branch of physics. It is defined as the capacity of a physical system to perform work. And it exists in several forms such kinetic, potential, thermal, chemical and other forms. And its SI unit is joule (J).

Kinetic energy (KE) is the capacity of an object to do work by virtue of its motion. For an object of mass *m* and moving with speed *v*, the kinetic energy is calculated as:

$$KE\ \frac{1}{2}mv^2$$

Potential Energy (PE) is the energy that is stored in an object due to its position relative to some zero position. An object possesses gravitational potential energy if it is positioned at a height above (or below) the zero height. The potential energy concept can be used only when dealing with a special class of forces called *conservative forces*.



Mathematically the potential energy is given by

$$\Delta U_g = mg\Delta y \text{---------- (2.3.5)}$$

This equation is valid only for objects near the surface of the Earth, where g is approximately constant

Work- Energy theorem

Self Diagnostic Test

If the work is done on a system, the work done appears as an increase in the energy of the system.

- What types of energy do you know?
- Can you state the work-kinetic energy theorem?

One of the possible outcomes of doing work on a system is that the system changes its speed. We have discussed how to find the work done on a particle by the forces that act on it, but how is that work manifested in the motion of the particle? According to Newton's second law of motion, the sum of all the forces acting on a particle, or the net force, determines the product of the mass and the acceleration of the particle, or its motion. Therefore, we should consider the work done by all the forces acting on a particle, or the network, to see what effect it has on the particle's motion.
Let a force '*F*' is applied on an object initially moving with velocity '*u'*. If it is displaced to a displacement 's' and changes its velocity into '*v*', then its motion will be expressed by:

$v^2 - u^2 = 2as$

Multiplying this equation by 'm' and dividing throughout by 2, we get:

$$\frac{mv^2}{2} - \frac{mu^2}{2} = mas;$$

Hence, $\frac{mv^2}{2} - \frac{mu^2}{2} = Fs$; where F is the force that caused the havoc!

Therefore, we can write, $\frac{mv^2}{2} - \frac{mu^2}{2} = W$; where $W = Fs$ is the work done by this force.

So what just happened? We just proved that, $\frac{1}{2}(mv^2) - \frac{1}{2}(mu^2)$ is the work done by the force! In other words, the work done is equal to the change in K.E. of the object! This is the Work-Energy theorem

or the relation between Kinetic energy and Work done. In other words, the work done on an object is the change in its kinetic energy.

$$W_{net} = \Delta K.E \ldots\ldots\ldots\

The mechanical energy of an isolated, friction-free system is conserved. An isolated system is one for which there are no energy transfers across the boundary. For the an object of mass m falling in a gravitational field

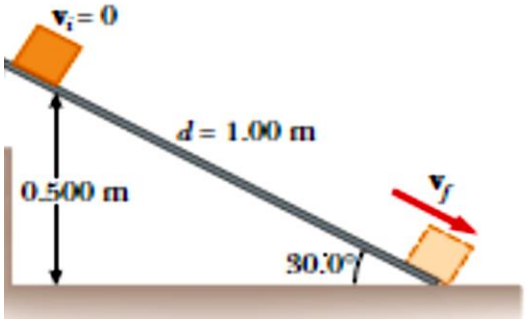
$$\frac{1}{2}mv_f{}^2 + mgy_f = \frac{1}{2}mv_i{}^2 + mgy_i$$

Activity

A ball of mass *m* is dropped from a height *h* above the ground. Neglecting air resistance, (a) determine the speed of the ball when it is at a height *y* above the ground. (b) Determine the speed of the ball at *y* if at the instant of release it already has an initial upward speed v_i at the initial altitude *h*.

Example

A 3.00-kg crate slides down a ramp. The ramp is 1.00m in length and inclined at an angle of 30.0°, as shown in the figure below. The crate starts from rest at the top, experiences a constant friction force of magnitude 5.00 N, and continues to move a short distance on the horizontal floor after it leaves the ramp. Use energy methods to determine the speed of the crate at the bottom of the ramp.



Solution

Since the non-conservative force (friction force) exists in the system,

$$\Delta K + \Delta U = -f_k d$$

$$K_f - K_i + U_f - U_i = -f_k d$$

$$\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 + mgh_f - mgh_i = -(5N)(1m)$$

$$\frac{1}{2}mv_i^2 = mgh_f = 0 \; because \; both \; v_i = h_f = 0$$

$$\frac{1}{2}(3kg)v_f^2 - (3kg)(9.8m/s^2)(0.5m) = -5J$$

$$v_f^2 = 6.47 \ \rightarrow v_f = 2.54m/s$$

2.3.2. Power

Power is defined as the time rate of energy transfer. If an external force is applied to an object (which we assume acts as a particle), and if the work done by this force in the time interval Δt is *W*, then the average power during this interval is defined as

$$P_{av} = \frac{W}{\Delta t} \text{---------- (2.3.7)}$$

The instantaneous power P is defined as the limiting value of the average power as Δt approaches zero:

$$P = \lim_{\Delta t \to o} \frac{W}{\Delta t} = \frac{W}{t} \text{---------- (2.3.8)}$$

But, $W = \boldsymbol{F}.\triangle \boldsymbol{r}$

$$P = \frac{W}{\triangle t} = \vec{F}.\frac{\triangle \vec{r}}{\triangle t} = \vec{F}.\vec{v} \text{---------- (2.3.9)}$$

In general, power is defined for any type of energy transfer. Therefore, the most general expression for power is

$$P = \frac{E}{t} \text{---------- (2.3.10)}$$

The SI unit of power is joules per second (J/s), also called the watt (W) (after James Watt):

$$1W = \frac{1J}{s} = 1kg.\frac{m^2}{s^3}$$

A unit of power in the U.S. customary system is the horsepower (hp):

$$1hp = 746W$$

A unit of energy (or work) can now be defined in terms of the unit of power. One kilowatt-hour (kWh) is the energy transferred in 1 h at the constant rate of 1 kW = 1 000 J/s. The amount of energy represented by 1 kWh is:

$$1kWh = (10^3W)(3600s) = 3.6 \times 10^6J$$

Example

An older model car accelerates from rest to speed *v* in 10 seconds. A newer, more powerful car accelerates from rest to 2*v* in the same time period. What is the ratio of the power of the newer car to that of the older car?

Solution

$$P_{av} = \frac{W}{\Delta t}$$

$$W_{old} = \Delta K = \frac{1}{2}mv_f{}^2 - \frac{1}{2}mv_i{}^2 = \frac{1}{2}mv^2$$

$$W_{new} = \Delta K = \frac{1}{2}mv_f{}^2 - \frac{1}{2}mv_i{}^2 = \frac{1}{2}m(2v)^2 = 2mv^2$$

$$P_{old} = \frac{W_{old}}{\Delta t} = \frac{mv^2}{2(\Delta t)} \quad and\ P_{new} = \frac{W_{new}}{\Delta t} = \frac{2mv^2}{\Delta t}$$

$$\frac{P_{new}}{P_{old}} = \frac{(\frac{2mv^2}{\Delta t})}{(\frac{mv^2}{2(\Delta t)})} = 4$$

Activity

The electric motor of a model train accelerates the train from rest to 0.620 m/s in 21.0cs. The total mass of the train is 875 g. Find the average power delivered to the train during the acceleration.

2.3.3. Linear Momentum

Momentum is defined as the quality of a moving object to exert a force on anything that tries to stop it. The linear momentum of a particle or an object that can be modeled as a particle of mass *m* moving with a velocity $\vec{v}$is defined to be the product of its mass and velocity:

$$\vec{P} = m\vec{v} \quad \text{---------- (2.3.11)}$$

Momentum ($\vec{P}$) is a vector quantity in the direction of the velocity with SI unit *kgm/s*.

Using Newton's second law of motion, we can relate the linear momentum of a particle to the resultant force acting on the particle.

$$\vec{F} = m\frac{\triangle\,\vec{v}}{\triangle\,t} \implies \vec{F} = \frac{\triangle\,(m\vec{v})}{\triangle\,t} = \frac{\triangle\,\vec{P}}{\triangle\,t}$$

Therefore, the time rate of change of the linear momentum of a particle is equal to the net force acting on the particle.

$$\triangle\,\vec{P} = \vec{F}\,\triangle\,t$$

$$\vec{I}(Impulse) = \Delta\vec{P} = \vec{P}_f - \vec{p}_i = \overrightarrow{F}\,\triangle\,t \text{ ---------- (2.3.12)}$$

The impulse of the net force $\vec{F}$ acting on the particle is equal to the change in momentum of the particle.

Conservation of Linear Momentum

Recall Newton's third law: When two objects of masses m_1 and m_2 interact (meaning that they apply forces on each other), the force that object 2 applies to object 1 is equal in magnitude and opposite in direction to the force that object 1 applies on object 2.

Let:

- $\vec{F}_{21}$= the force on m_1 from m_2
- $\vec{F}_{12}$ = the force on m_2 from m_1

Then, in symbols, Newton's third law says

$$\vec{F}_{12} = -\vec{F}_{21}$$

$$\vec{F}_{12} + \vec{F}_{21} = 0$$

$$m_1 \frac{\triangle \vec{v}_1}{\triangle t} + m_2 \frac{\triangle \vec{v}_2}{\triangle t} = 0$$

$$\Longrightarrow m_1 \Delta \vec{v}_1 + m_2 \Delta \vec{v}_2 = 0$$

$$\Longrightarrow m_1 \vec{v}_{1i} + m_2 \vec{v}_{2i} = m_1 \vec{v}_{1f} + m_2 \vec{v}_{2f}$$

$$\vec{P}_{1i} + \vec{P}_{2i} = \vec{P}_{1f} + \vec{P}_{2f} \quad \text{---------- (2.3.13)}$$

$$\vec{P}_{tot} = \vec{P}_1 + \vec{P}_2 = constant$$

Where $\vec{P}_{1i}$and $\vec{P}_{2i}$are the initial values and $\vec{P}_{1f}$ and $\overrightarrow{P}_{2f}$the final values of the momenta for the two particles for the time interval during which the particles interact.

This result, known as the law of conservation of linear momentum, can be extended to any number of particles in an isolated system. We can state it as follows: "*Whenever two or more particles in an isolated system interact, the total momentum of the system remains constant".*

Example 1

A 60-kg archer stands at rest on frictionless ice and fires a 0.50-kg arrow horizontally at 50 m/s. With what velocity does the archer move across the ice after firing the arrow?

Solution

Let m_1 be mass of the archer

$$m_2 \; be \; mass \; of \; the \; arrow$$

If we consider the archer+ arrow as isolated system

$$\vec{P}_{tot} = constant \rightarrow \vec{P}_i = \vec{P}_f$$

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$

$v_{1i} = v_{2i} = 0$, *Because initially the archer +arrow is at rest*

$$0 = 60kg v_{1f} + (0.5kg)(50m/s)$$

$$v_{1f} = \frac{-25}{60} = -0.42m/s$$

Activity

1. A ball of mass 0.150 kg is dropped from rest from a height of 1.25 m. It rebounds from the floor to reach a height of 0.960 m. What impulse was given to the ball by the floor?

2.3.4. Collisions

Self Diagnostic Test

What is the difference between elastic, inelastic and perfectly inelastic collision?

Consider the collision between two particles of masses m_1 and m_2 shown in the figure below. If the two particles form an isolated system, the momentum of the system must be conserved. Therefore, the total momentum of an isolated system just before a collision equals the total momentum of the system just after the collision. But, the total kinetic energy of the system of particles may or may not be conserved, depending on the type of collision. Whether or not kinetic energy is conserved is used to classify collisions as either *elastic* or *inelastic*.

A. Elastic collision: - An elastic collision between two objects is one in which the total kinetic energy as well as total momentum of the system is conserved.

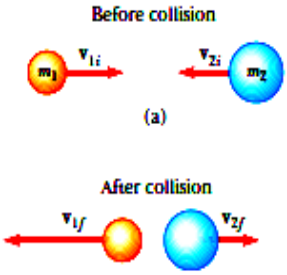
Perfectly elastic collisions occur between atomic and subatomic particles.

Consider two particles of masses m_1 and m_2 moving with initial velocities $v_{1i}$and v_{2i}along the same straight line, as shown in the figure below. The two particles collide head-on and then leave the collision site with different velocities, $v_{1f}$and v_{2f}. If the collision is elastic, both the

momentum and kinetic energy of the system are conserved. Therefore, considering velocities along the horizontal direction we have:

$$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f} \quad \text{---------- (2.3.14)}$$

$$\frac{1}{2}m_1v_{1i}^2 + \frac{1}{2}m_2v_{2i}^2 = \frac{1}{2}m_1v_{1f}^2 + \frac{1}{2}m_2v_{2f}^2 \quad \text{---------- (2.3.15)}$$



Because all velocities in the figure are either to the left or the right, they can be represented by the corresponding speeds along with algebraic signs indicating direction. We shall indicate *v* as positive if a particle moves to the right and negative if it moves to the left.

From conservation of kinetic energy,

$$\frac{1}{2}m_1v_{1i}^2 + \frac{1}{2}m_2v_{2i}^2 = \frac{1}{2}m_1v_{1f}^2 + \frac{1}{2}m_2v_{2f}^2$$

We can cancel the factor $\frac{1}{2}$in the equation, and rewrite as

$$m_1\left(v_{1i}^2 - v_{1f}^2\right) = m_2(v_{2f}^2 - v_{2i}^2)$$

Then, factor both sides

$$m_1\left(v_{1i} - v_{1f}\right)\left(v_{1i} + v_{1f}\right) = m_2\left(v_{2f} - v_{2i}\right)\left(v_{2f} + v_{2i}\right)\text{(a)}$$

Separate the terms containing $m_1$andm_2

$$m_1\left(v_{1i} - v_{1f}\right) = m_2\left(v_{2f} - v_{2i}\right)\text{(b)}$$

Dividing equation (a) by equation (b)

$$v_{1i} + v_{1f} = v_{2f} + v_{2i}$$

$$v_{1i} - v_{2i} = -(v_{1f} - v_{2f}) \quad \text{---------- (2.3.16)}$$

Equation (5.6) along with equation (5.4) can be used to solve problems dealing with elastic collisions.

B. Inelastic Collision: - An inelastic collision is one in which the total kinetic energy of the system is not conserved. But the momentum of the system is conserved. Therefore, for inelastic collision of two particles:

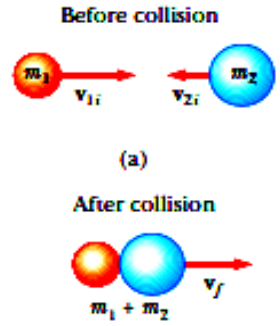
$$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$$

$$\frac{1}{2}m_1v_{1i}^2 + \frac{1}{2}m_2v_{2i}^2 \neq \frac{1}{2}m_1v_{1f}^2 + \frac{1}{2}m_2v_{2f}^2$$

C. Perfectly Inelastic Collision: -When the colliding objects stick together after the collision, the collision is called perfectly inelastic. Consider two particles of masses

$m1$ and $m2$ moving with initial velocities $v_{1i}$and v_{2i}along the same straight line, as shown in the figure below.

The two particles collide head-on, stick together, and then move with some common velocity $v_f$after the collision.



The total momentum before the collision equals the total momentum of the composite system after the collision

$$m_1v_{1i} + m_2v_{2i} = (m_1 + m_2)v_f$$

gives

$$v_f = \frac{m_1v_{1i}+m_2v_{2i}}{m_1+m_2} \quad \text{---------- (2.3.17)}$$

Example 1

An archer shoots an arrow toward a target that is sliding toward her with a speed of 2.50 m/s on a smooth surface. The 22.5-g arrow is shot with a speed of 35.0 m/s and passes through the 300-g target, which is stopped by the impact. What is the speed of the arrow after passing through the target?

Solution

From conservation of linear momentum

$$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$$

$$(22.5g)\left(\frac{35m}{s}\right) + (300g)(-\frac{2.5m}{s}) = (22.5g)v_{1f} + 0$$

$$v_{1f} = \left(\frac{787.5 - 750}{22.5}\right)\frac{gm/s}{g}$$

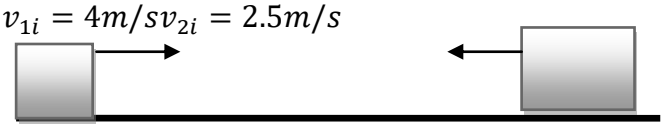
$$v_{1f} = 1.67m/s$$

Example 2

A block of mass $m_1 = 1.6kg$ initially moving to the right with a speed of 4m/s on a horizontal frictionless track collides with a second block of mass $m_2 = 2.1kg$ initially moving to the left with a speed of 2.5m/s. If the collision is elastic, find the velocities of the two blocks after collision.

Solution

$v_{1i} = 4m/s v_{2i} = 2.5m/s$



Before Collision

We are given that We are asked to find v_{1f} & v_{2f}

$m_1 = 1.6kg, v_{1i} = 4m/s$ *Since the collision is elastic both momentum and*

$m_2 = 2.1kg, v_{2i} = -\frac{2.5m}{s}$ *kinetic energy are conserved*

From conservation of momentum

$$(1.6kg)(4m/s) + (2.1kg)(-2.5m/s) = (1.6kg)v_{1f} + (2.1kg)v_{2f}$$

$$1.6v_{1f} + 2.1v_{2f} = 1.15 \quad \text{(a)}$$

From conservation of kinetic energy

$$v_{1i} + v_{1f} = v_{2i} + v_{2f}$$

$$v_{1f} - v_{2f} = v_{2i} - v_{1i}$$

$$v_{1f} - v_{2f} = -2.5m/s - 4m/s$$

$$v_{1f} - v_{2f} = -6.5m/s \text{ (b)}$$

Solving equation (a) and (b) simultaneously

$$v_{1f} = -3.38m/s$$

$$v_{2f} = 3.12m/s$$

Activity

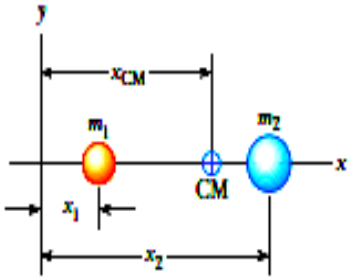
A 10.0-g bullet is fired into a stationary block of wood (m = 5.00 kg).The bullet sticks into the block, and the speed of the bullet-plus-wood combination immediately after the collision is 0.600 m/s. What was the original speed of the

2.3.5. Center of Mass

Self Diagnostic Test

What do we mean by the center of mass?

The center of mass is the point at which all the mass can be considered to be "concentrated". The center of mass of the system is located somewhere on the line joining the particles and is closer to the particle having the larger mass. The center of mass of the pair of particles located on the *x* axis as shown in the figure below lies somewhere between the particles, it is given by:



$$x_{CM} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$$

We can extend this concept to a system of many particles with masses $m_i$in three dimensions. The *x* coordinate of the center of mass of *n* particles is defined to be

$$x_{CM} = \frac{m_1 x_1 + m_2 x_2 + m_3 x_3 \ldots + m_n x_n}{m_1 + m_2 + m_3 \ldots + m_n} = \frac{\sum_i m_i x_i}{\sum_i m_i} = \frac{\sum_i m_i x_i}{M} \text{---------- (2.3.18)}$$

Similarly, the *y* and *z* coordinates of the center of mass are

$$y_{CM} = \frac{\sum_i m_i y_i}{M} \quad and \quad z_{CM} = \frac{\sum_i m_i z_i}{M} \text{---------- (2.3.19)}$$

Therefore,

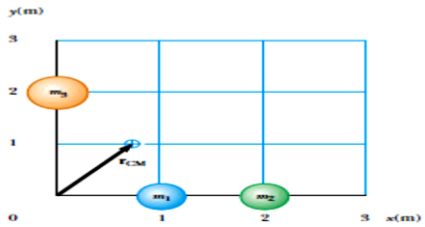
$$\vec{r}_{CM} = x_{CM}\hat{\imath} + y_{CM}\hat{\jmath} + z_{CM}\hat{k} = \frac{\sum_i m_i x_i \hat{\imath} + \sum_i m_i y_i \hat{\jmath} + \sum_i m_i z_i \hat{k}}{M}$$

$$\vec{r}_{CM} = \frac{\sum_i m_i \vec{r}_i}{M} \text{---------- (2.3.20)}$$

Example 1

A system consists of three particles with masses $m_1 = m_2 = 1.0kg$ and $m_2 = 2.0kg$ located as shown in the figure below. Find the center of mass of the system.

Solution



$$x_{CM} = \frac{m_1 x_1 + m_2 x_2 + m_3 x_3}{m_1 + m_2 + m_3}$$

$$x_{CM} = \frac{(1kg)(1m) + (1kg)(2m) + (2kg)(0m)}{1kg + 1kg + 2kg}$$

$$x_{CM} = 0.75m y_{CM} = \frac{m_1 y_1 + m_2 y_2 + m_3 y_3}{m_1 + m_2 + m_3}$$

$$y_{CM} = \frac{(1kg)(0m) + (1kg)(0m) + (2kg)(2m)}{1kg + 1kg + 2kg}$$

$$y_{CM} = 1m$$

Activity

Four objects are situated along the *y* axis as follows: a 2.00 kg object is at +3.00 m, a 3.00-kg object is at +2.50 m, a 2.50-kg object is at the origin, and a 4.00-kg object is at -0.500 m. Where is the center of mass of these objects?

Chapter Summery

Kinematics is the study of motion of objects without considering the agents that cause the motion, and **Dynamics** is the study of motion of objects with the cause of the motion.

For motion with constant acceleration,

$$\vec{v} = \vec{u} + \vec{a}t \quad \text{(a)} \qquad \vec{v}_{av} = \frac{\vec{v}+\vec{u}}{2}$$

$$\vec{r}_f - \vec{r}_{i\,=} \vec{u}t + \frac{1}{2}\vec{a}t^2 \text{ (c)} \qquad v^2 = u^2 + 2a\Delta r$$

Projectile motion is a motion in a curved path in a gravitational field.

The maximum height of the projectile is given by

$$h = \frac{u^2 sin^2\theta}{2g}$$

The Range(R) is the horizontal displacement of the projectile covered in a total time of flight

$(t_{tot} = \frac{2usin\theta}{g})$ $\quad is:\ R = \frac{u^2 sin2\theta}{g}$

Force: any interaction that changes the motion an object.

Friction force is always proportional to the normal force between the two interacting surfaces.

$$\boldsymbol{F_{frict} \propto F_{norm}} \longrightarrow \boldsymbol{F_f} = \mu F_N$$

There are two types of frictional force: *Static friction, Kinetic friction*:

Uniform Circular Motion is motion of objects in a circular path with a constant speed. For objects moving in a circular path with a constant speed, acceleration arises because of the change in direction of the velocity, and such acceleration is called the **centripetal acceleration**

$$a_c = \frac{v^2}{r}$$

Newton's universal law of gravitation states that the force is directly proportional to the product of their masses and inversely proportional to the square of the distance between them

$$\vec{F} = \frac{GmM}{r^2}\hat{\mathrm{r}}\,.$$

Weightlessness is simply a sensation experienced by an individual when there are no external objects touching one's body and exerting a push or pull upon it.

The work (W) done on a system by an agent exerting a constant force ($\vec{F}$)and moving the system through the displacement ($\Delta\vec{r}$) is

$$W = \vec{F}.\Delta\vec{r} = |\vec{F}||\Delta\vec{r}|\cos\theta$$

Kinetic energy is represents the energy associated with the motion of the particle: $K = \frac{1}{2}mv^2$

Potential energy is the energy associated with the configuration of a system of objects that exert forces on each other. The potential energy concept can be used only when dealing with a special class of forces called ***conservative forces.*** $U_g = mgy$

Power is defined as the time rate of energy transfer:$P_{av} = \frac{W}{\Delta t}$

Momentum is defined as the quality of a moving object to exert a force on anything that tries to stop it.

The **center of mass** is the point at which all the mass can be considered to be "concentrated".

Chapter Review Questions and Problems

1. A fish swimming in a horizontal plane has velocity $\vec{v}_i = (4\hat{\imath}+\hat{\jmath})$ m/s at a point in the ocean where the position relative to a certain rock is $\vec{r}_i = (10\hat{\imath}-4\hat{\jmath})$ m. After the fish swims with constant acceleration for 20s, its velocity is $\vec{v}_f = (20\hat{\imath}-5\hat{\jmath})$ m/s.
    a) Find the acceleration of the fish
    b) If the fish maintains this constant acceleration, where is it at t=25s?
2. A projectile is fired in such a way that its horizontal range is equal to three times its maximum height. What is the angle of projection?
3. Two projectiles are thrown with the same initial velocity, one at an angle θ and the other at an angle of $90^0 - \theta$. (a) Can both projectiles strike the ground at the same distance from the projection point? (b) Can both projectiles be in air for the same time interval?
4. A ball of mass 0.200 kg has a velocity of 150m/s; a ball of mass 0.300 kg has a velocity of -0.4m/s. They meet in a head-on elastic collision. (a) Find their velocities after the collision. (b) Find the velocity of their center of mass before and after the collision.
5. Four objects are situated along the *y* axis as follows: a 2.00 kg object is at +3.00 m, a 3.00-kg object is at +2.50 m, a 2.50-kg object is at the origin, and a 4.00-kg object is at -0.500 m. Where is the center of mass of these objects?

CHAPTER THREE

FLUID MECHNICS

Fluid mechanics is the branch of **physics** concerned with the **mechanics** of **fluids** in motion (fluid *dynamics*) or at rest (fluid *statics*) and the forces on them. This study area deals with many and diversified problems such as surface tension, fluid statics, flow in enclose bodies, or flow round bodies (solid or otherwise), flow stability, etc. The applications of fluid mechanics are enormous: breathing, blood flow, swimming, pumps, fans, turbines, airplanes, ships, rivers, windmills, pipes, missiles, icebergs, engines, filters, jets, and sprinklers, to name a few. In **physics**, a **fluid** is a substance that continually deforms (flows) under an applied shear stress, or external force. **Fluids** are a phase of matter and include **liquids** and gases.

Learning Objectives

At the end of this unit, you will be able to:

- Distinguish between elastic and plastic materials properties.
- Define the three kinds of stresses, strains and elastic moduli (tensile, shear and volume) and then apply them to solve problems.
- Distinguish between density, weight density, and specific gravity and given an object's mass and volume, calculate the object's density, weight density, and specific gravity.
- Calculate the pressure acting at a depth h below the surface of a liquid of density (ρ).
- Distinguish between absolute pressure and gauge pressure.
- State Pascal's principle and apply this principle to basic hydraulic systems.
- State Archimedes' principle and use this principle to solve problems related to buoyancy.
- Explain equation of continuity and Bernoulli's equation and apply to solve problems.

3.1. Properties of Bulk Matter

Self Diagnostic Test

- Can you differentiate what elastic and inelastic behaviors?
- What are stress and strain?
- Can you define pressure?

Although a solid may be thought of as having a definite shape and volume, it's possible to change its shape and volume by applying external forces. A sufficiently large force will permanently deform or break an object, but otherwise, when the external forces are removed, the object tends to return to its original shape and size. This is called **elastic behavior**.

Definitions:

Elastic materials are materials that regain their original shape and size when the deforming force is removed.

Elastic deformation is a reversible deformation by a force applied within the elastic limit. Beyond elastic limit, a force applied on an object causes permanent and irreversible deformation called **plastic deformation**.

Plastics materials: do not regain their original shape and size when the deforming force is removed. The elastic properties of solid materials are described in terms of **stress** and **strain**. **Stress is the force per unit area that is causing some deformation** on an object. It has SI unit N/m^2 called the Pascal (Pa), the same as the unit of pressure.

$$Stress = \frac{F}{A} \quad \text{(3.1)}$$

Strain-measures the amount of deformation by the applied stress and defined as the change in configuration of a body divided by its initial configuration. Strain is unit less quantity.

$$Strain = \frac{Change\ in\ configuration}{Initial\ configuration} \quad \text{(3.2)}$$

There are three kinds of strains:

1. Tensile Strain:

When the ends of a bar(rod or wire) of uniform cross-sectional area A are pulled with equal and opposite forces of magnitude $F_\perp$ (Figure 1(a)), the bar will undergo a stretch by the tensile stress defined as the ratio of the force magnitude $F_\perp$ to the cross-sectional area A:

$$Tensile\ stress = \frac{F_\perp}{A} \quad \text{(3.3)}$$

The fractional change in length of an object under a tensile stress is called the tensile strain (Figure 1b)

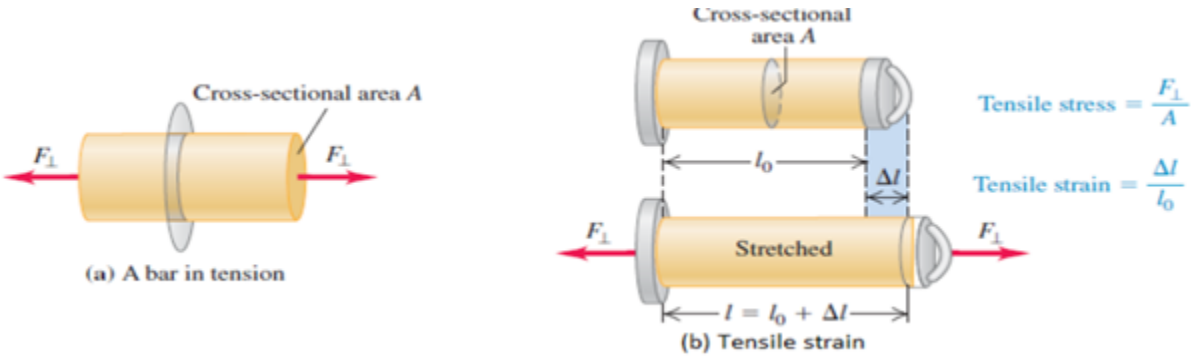


Figure 3.1: Shows a bar's a) tensile stress and b) tensile strain

$$Tensile\ strain = \frac{\Delta l}{l_0} \quad \text{.....(3.4)}$$

2. Shear Stress and Strain

Another type of deformation occurs when an object is subjected to a force parallel to one of its faces while the opposite face is held fixed by another force (Figure 3.2a). The stress in this case is called a shear stress. If the object is originally a rectangular block, a shear stress results in a shape whose cross section is a parallelogram. A book pushed sideways, as shown in Figure 3.2b, is an example of an object subjected to a shear stress. To a first approximation (for small distortions), no change in volume occurs with this deformation. We define the shear stress as F/A, the ratio of the tangential force to the area A of the face being sheared.

$$Shear\ stress = \frac{\Delta F}{A} \quad \text{.....(3.5)}$$

The shear strain is defined as the ratio x/h, where x is the horizontal distance that the sheared face moves and h is the height of the object. Interms of these quantities, the shear modulus is

$$Shear\ strain = \frac{x}{h} = \tan\phi \quad \text{.....(3.6)}$$

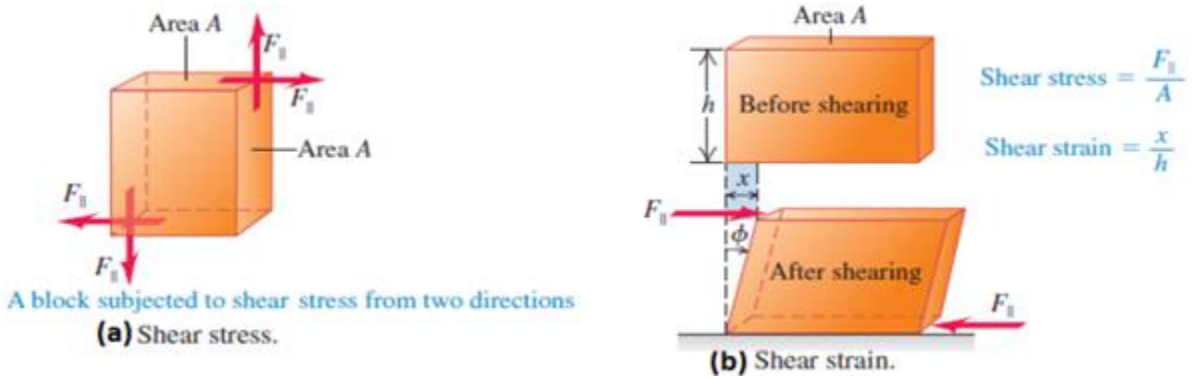


Figure 3.2: Shows an object deformed by a shear stress, a) shear stress and b) shear strain

3. **Volume Stress and Strain**

Volume Stress is a stress which causes volume deformation on an object and defined as the ratio of the change in the magnitude of the applied force ΔF to the surface area A.

$$Volume\ stress = \frac{\Delta V}{V_0} \text{.....(3.7)}$$

Volume strain is the fractional change in volume (Figure 3) that is - the change in volume, ΔV , divided by the original volume V_0:

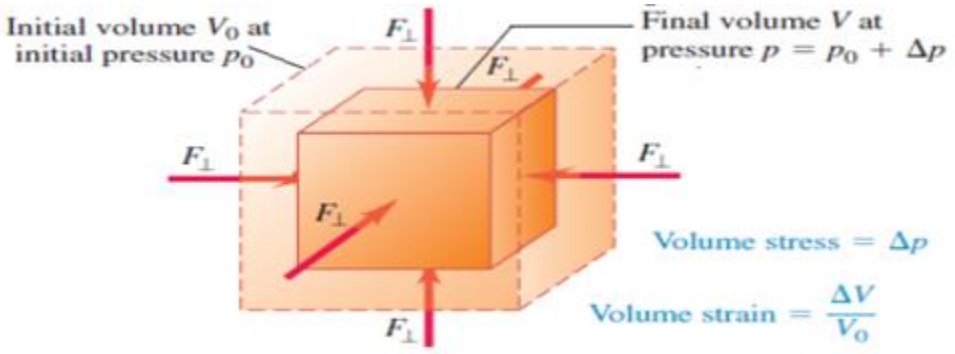

Initial volume V_0 at initial pressure p_0
Final volume V at pressure $p = p_0 + \Delta p$
Volume stress = Δp
Volume strain = $\frac{\Delta V}{V_0}$

Figure 3.3: A block undergoing volume strain by the applied volume stress

Elasticity Moduli

The stress will be proportional to the strain if the stress is sufficiently small. In this regard, the proportionality constant known as **elastic modulus** depends on the material being deformed and on the nature of the deformation.

$$Stress = elastic\ modulus \times strain \text{---------- (3.8)}$$

This relationship between stress and strain is analogous to Hooke's law ($F = -k\Delta x$), relationship between force and extension of a spring. The elastic modulus is analogous to a spring constant.

Corresponding to the three types of strains, there are three types of elastic module.

1. Young's Modulus: is the ratio of the tensile stress to the tensile strain. It measures the resistance of a solid to a change in its length and typically used to characterize a rod or wire stressed under either tension or compression. Note that because strain is a dimensionless quantity, Y has units of force per unit area. Typical values are given in Table 3.1. Experiments show (a) that for a fixed applied force, the change in length is proportional to the original length and (b) that the force necessary to produce a given strain is proportional to the cross-sectional area.

$$Y = \frac{tensile\ stress}{tensile\ strain} = \frac{F_{\perp}/A}{\Delta l/l_0} \text{ ---------- -(3.9)}$$

2. Shear Modulus (S): with units of Pascal, is the ratio of shear stress to shear strain. It is the measure of the resistance to motion of the planes within a solid parallel to each other. A material having a large shear modulus is difficult to bend. Values of the shear modulus for some representative materials are given in Table 3.1.Like Young's modulus, the unit of shear modulus is the ratio of that for force to that for area.

$$S = \frac{Shear\ stress}{Shear\ strain} = \frac{F_{\parallel}/A}{x/h} \text{ ----------(3.10)}$$

3. **Bulk Modulus**: its SI unit is Pascal, is the ratio of the volume stress to the volume strain. Bulk modulus measures the resistance of solids or liquids to changes in their volume. A material having a large bulk modulus doesn't compress easily. Note that a negative sign is included in this defining equation so that B is always positive. An increase in pressure (positive ΔP) causes a decrease in volume negative ΔV) and vice versa.

$$B = \frac{Volume\ stress}{Volume\ strain} = \frac{-\Delta F/A}{\Delta V/V_0} = \frac{-\Delta P}{\Delta V/V_0} \text{ ----------(3.11)}$$

A negative sign is inserted in this defining equation so that B is a positive number. This maneuver is necessary because an increase in pressure (positiveΔP) causes a decreasein volume (negativeΔV) and vice versa. Table 3.1 lists bulk moduli for some materials. If you look up such values in a different source, you often find that the reciprocal of the bulk modulus is listed. The reciprocal of the bulk modulus is called the compressibility of the material. Note from Table 12.1 that both solids and liquids have a bulk modulus. However, no shear modulus and no Young's modulus are given for liquids because a liquid does not sustain a shearing stress or a tensile stress. If a shearing force or a tensile force is applied to a liquid, the liquid simply flows in response.

- Strain Energy is energy stored in a stretched wire. If x is the stretch due to applied force F,

$$Strain\ energy = \frac{1}{2}kx^2 \quad \text{---------- (3.12)}$$

Table 3.1: Typical Values for Elastic Moduli

Typical Values for Elastic Moduli			
Substance	**Young's Modulus (N/m^2)**	**Shear Modulus (N/m^2)**	**Bulk Modulus (N/m^2)**
Tungsten	35×10^{10}	14×10^{10}	20×10^{10}
Steel	20×10^{10}	8.4×10^{10}	6×10^{10}
Copper	11×10^{10}	4.2×10^{10}	14×10^{10}
Brass	9.1×10^{10}	3.5×10^{10}	6.1×10^{10}
Aluminum	7.0×10^{10}	2.5×10^{10}	7.0×10^{10}
Glass	$6.5–7.8 \times 10^{10}$	$2.6–3.2 \times 10^{10}$	$5.0–5.5 \times 10^{10}$
Quartz	5.6×10^{10}	2.6×10^{10}	2.7×10^{10}
Water	—	—	0.21×10^{10}
Mercury	—	—	2.8×10^{10}

Example:

Suppose that the tension in the cable is 940 N as the actor reaches the lowest point. What diameter should a 10-m-long steel wire have if we do not want it to stretch more than 0.5 cm under these conditions?

Solution:

From the definition of Young's modulus, we can solve for the required cross-sectional area. Assuming that the cross section is circular, we can determine the diameter of the wire. From Equation:

$$Y = \frac{F_{\perp}/A}{\Delta l/l_0} \quad \Longrightarrow A = \frac{Fl_0}{Y\Delta l} = \frac{(940\ \mathrm{N})(10\ \mathrm{m})}{\left(20 - 1010\frac{N}{m^2}\right)(0.005\ m)} = 9.4 \times 10^{-6} m^2$$

Because $A = \pi r^2$ the radius of the wire can be found from ,

$$r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{9.4 \times 10^{-6} m^2}{\pi}} = 1.7 \times 10^{-3} m = 1.7m$$

$$d = 2r = 2(1.7mm) = 3.4\ mm$$

Activity: A solid brass sphere is initially surrounded by air, and the air pressure exerted on it is $1.0 \times 10^5 N/m^2$ (normal atmospheric pressure). The sphere is lowered into the ocean to a depth where the pressure is $2.0 \times 10^7 N/m^2$. The volume of the sphere in air is 0.50 m3. By how much does this volume change once the sphere is submerged?

3.2. Density and Pressure in Static Fluids

Density (ρ) is the quantity of mass (m) per unit volume (V) of a body with SI unit$\mathrm{kg/m^3}$ and given by: $\rho = \frac{m}{V}$ ---------- *(3.13)*

Specific gravity (SG): is the ratio of the density of the substance to the density of another substance which is taken as a standard. The density of pure water at 4^0C is usually taken as the standard and this has been defined to be exactly$1.0 \times 10^3\ kg/m^3$. Specific gravity is a dimensionless quantity and the same in any system of measurement. For example, the density of aluminum is $2.7 \times 10^3\ kg/m^3$; therefore, the SG of aluminum is SG = $2.7 \times \frac{10^3 kg/m^3}{1.0 \times 10^3 kg/m^3} =$ 2.7.

Example:

A solid sphere made of wood has a radius of 0.1 m. The mass of the sphere is 1.0 kg. Determine a) density and b) specific gravity of the wood.

Solution:

The volume of the sphere wood, $V = \frac{4}{3}\pi\, r^3 = \frac{4}{3} \times 3.14 \times (0.1)^3 = 4.18 \times 10^{-3} m^3$.

a) The density of the wood, $\rho = \frac{m}{V} = \frac{1.0\ kg}{4.18 \times 10^{-3} m^3} = 239\ kg/m^3$.

b) The specific gravity of the wood, $SG = \frac{mdensity\ of\ wood}{density\ of\ water} = \frac{239 kg/m^3}{1000\ kg/m^3} = 0.239$

Pressure is the ratio of the force acting perpendicular to s surface to the surface area (A) on which the force acts. SI unit of pressure is N/m^2, called Pascal (Pa). Another commonly used pressure unit is atmosphere (atm) equal to 101.3 kPa, which is the average pressure, exerted by the Earth's atmosphere at sea level.

$$P = \frac{F_{\perp}}{A} \quad \text{.....(3.14)}$$

- The pressure produced by the column of fluid of height h and density ρ is given by:

$$P_{fluid} = \rho g h \quad \text{.....(3.15)}$$

The density of liquids and solids is considered to be constant. In reality, the density of a liquid will increase slightly with increasing depth (Why?). The variation in density is usually negligible and can be ignored.

Note that:

- All points at same level in a fluid have same pressure.
- Fluid pressure increases with increase in the depth of the fluid.
- Fluid pressure does not depend on the shape of the container.

Atmospheric Pressure: is the pressure due to the weight of the atmosphere exerted on the surface of the Earth. Atmospheric pressure decreases with increase in altitude as a result of decrease in the density of the air.

Gauge pressure: is the difference in pressure between a system and the surrounding atmosphere.

$$P_{guage} = P_{system} - P_{atmosphere} \text{..... (3.16)}$$

Because gauge pressure is the pressure relative to atmospheric pressure, therefore, it is positive for pressures above atmospheric pressure, and negative for pressures below it.

Absolute Pressure: In fact, atmospheric pressure does add to the pressure in any fluid not enclosed in a rigid container. This happens because of Pascal's principle. The total pressure, or absolute pressure, is thus the sum of gauge pressure and atmospheric pressure:

$$P_{absolute} = P_{gauge} + P_{atmospheric} \quad \text{(3.17)}$$

In most cases the absolute pressure in fluids cannot be negative. Fluids push rather than pull, so the smallest absolute pressure is zero. (A negative absolute pressure is a pull.) Thus the smallest possible gauge pressure is $P_{gauge} = -P_{atmosphere}$

Example:

A submerged wreck is located 18.3 m beneath the surface of the ocean off the coast of South Florida. Determine the a) gauge pressure and b) absolute pressure on a scuba diver who is exploring the wreck. Note: the density of sea water is $1025\ kg/m^3$.

Solution:

a) $P_{gauge} = \rho gh = (1025\ kg/m^3)(9.80\ m/s^2)(18.3\ m) = 1.83 \times \frac{10^5 N}{m^2} = 182\ kPa.$

b) $P_{abs} = P_{gau} + P_{atm} = (1.83 \times 10^5 + 1.013 \times 10^5)\, N/m^2 = 2.84 \times 10^5\, N/m^2 = 2.84 kPa$.

3.3. Buoyant Force and Archimedes' Principles

Pascal's Principle - sates that pressure applied to a confined fluid in a container is transmitted equally to all regions of the fluid and to the walls of the container. An important application of Pascal's principle is the hydraulic press (Figure 4). A downward force $\overrightarrow{F_1}$ applied to a small piston of areaA_1causes a pressure of $P_1 = {F_1}/{A_1}$. The pressure is transmitted throughout the fluid and reaches the larger piston of area A_2without any change.

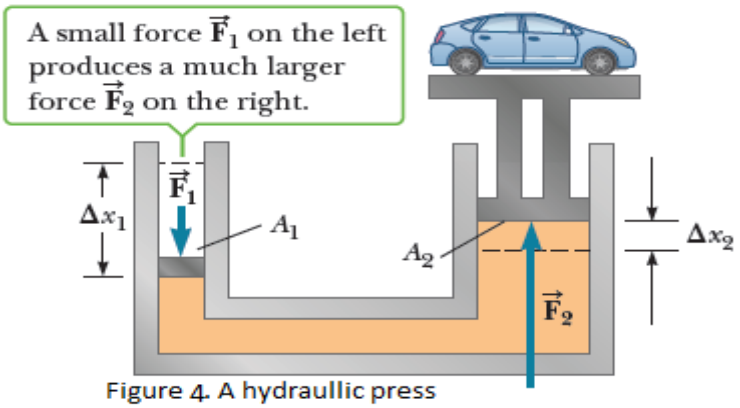


Figure 4. A hydraullic press

As the fluid moves it pushes the larger piston with $\overrightarrow{F_2}$ and exerts a pressure of $P_2 = {F_2}/{A_2}$.

AccordingtoPascal's principle, these two pressures are equal implying:

$${F_1}/{A_1} = {F_2}/{A_2} \quad \text{.....(3.18)}$$

Activity: Discuss in group what conclusion you can draw from the above equation about the output force and describe some applications of Pascal's principle.

Example:

The small piston of a hydraulic lift has an area of $0.20\ m^2$. A car weighing $1.2 \times 10^4 N$ sits on a rack mounted on the large piston. The large piston has an area of $0.90\ m^2$. How large force must be applied to the small piston to support the car?

Given:

$A_1 = 0.20\ m^2$

$A_2 = 0.90\ m^2$

$F_2 = 1.2 \times 10^4 N$

Unknown:

$F_1 = ?$

Solution:

$${F_1}/{A_1} = {F_2}/{A_2} \implies F_1 = F_2\left({A_1}/{A_2}\right)$$

$$= \left(1.2 \times 10^4 N\right)\left(\frac{0.90\ m^2}{0.20 m^2}\right)$$

$$= 2.7 \times 10^3 N$$

3.3.1. Archimedes' principle

Any object which is partially or totally submerged in a liquid has buoyant force acting on it which pushes the object up. That is why a rock appears to weigh less when it is submerged in liquid, or why it is very difficult to push a beach ball under water. The famous Greek mathematician, Archimedes' developed a principle which describes this around 250 B.C. Archimedes' principle can be stated as anybody completely or partially submerged in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the body.

$$F_{buoyant} = W_{fluid} = \rho_{fluid} V_{\substack{displaced \\ fluid}} g \quad \text{..... (3.19)}$$

Where, F_{buoyan} is the magnitude of the buoyant force and W_{fluid} is the weight of thedisplaced fluid. The reason for this is that the pressure of the fluid is dependenton the depth of the fluid. So the pressure at the top of an object is less than the pressure at the bottom of the object which creates a net force.

Activity: Discuss in group about the principles of floatation and explain for what conditions an object floats and sinks in a fluid.

Example:

A sample of an unknown material weighs 300 N in air and 200 N when submerged in an alcohol solution with a density of $0.70 \times 10^3\ kg/m^3$. What is the density of the material?

Given:
$W_{air} = 300\ N$
$W_{alcohol} = 200\ N$
$\rho_{alcohol} = 0.70 \times 10^3\ kg/m^3$

Unknown:
$\rho_{material}\ or\ \rho_O = ?$

Solution:
$F_{buo} = W_{air} - W_{alcohol} = 300N - 200N = 100\ N$

$$\frac{W_{air}}{F_{buoy}} = \frac{\rho_O}{\rho_{alcohol}} \implies \rho_O = \rho_{alcohol}\left(\frac{W_{air}}{F_{buoy}}\right)$$

$$= (0.70 \times 10^3\ kg/m^3)\left(\frac{300N}{100N}\right)$$

$$= 2.1 \times 10^3\ kg/m^3$$

3.4. Moving Fluids and Bernoulli Equations (Fluid Dynamics)

Up until this point, we have discussed fluids which are static. That is, they are not in motion. We now turn our attention to fluids in motion, or hydro dynamics. There are many categories of fluids in motion, categorized by whether the fluid flow is steady, or not steady, compressible or incompressible, viscous or non-viscous. In steady flow, the velocity of the fluid particles at any point is constant as time goes by. Different parts of the fluid may be flowing at different rates, but the fluid in one location is always flowing at the same rate. An in compressible flow is the flow of a fluid which cannot be compressed. Most liquids are nearly incompressible. A viscous fluid is one which does not flow easily, like honey, while a non-viscous fluid is one which flows more easily, like water. We will mostly be concerned with the steady flow of in compressible, non-viscous fluids.

If the flow is steady, then the velocity of the fluid particles at any point is a constant with time. The various layers of the fluid slide smoothly past each other. This is called streamline or laminar flow. It assumes that as each particle in the fluid passes a certain point it follows the same path as the particles that preceded it. There is no loss of energy due to internal friction in the fluid, which is the fluid, is assumed to travel smoothly in regular layers; the velocity and pressure remain constant at every point in the fluid.

Above some certain velocity, the flow is not smooth and becomes turbulent. Illustrations of turbulent and laminar flow are shown in Figure 3.5. Turbulent flow is the irregular movement of particles in a fluid and results in loss of energy due to internal friction between neighboring layers of the fluid, called viscosity. There is disruption to the layers of fluid; the speed of the fluid at any point is continuously changing both in magnitude and direction.

Factors affecting laminar flow are density, compressibility, temperature and viscosity of the fluid. Assumptions made in the ideal fluid flow to understand the complex motions of real fluids:

- The fluid is non-viscous, i.e there is no internal friction between adjacent layers.
- The flow is steady; the velocity of the fluid at each point remains constant.
- The fluid is incompressible; density of the fluid is constant.
- The flow is irrotational; the fluid has no angular momentum about any point.

Equation of Continuity

Equation of continuity expresses conservation of mass for an incompressible fluid flowing in a tube. It says:"***the amount (either mass or volume) of fluid flowing through a cross section of the tube in a given time interval must be the same for all cross sections***", or" ***the product of the area and the fluid speed at all points along a tube is constant for an incompressible fluid"*** (Figure 3.5).

$$Av = A_1v_1 = A_2v_2 \quad \text{(3.20)}$$

We see that if the cross sectional area is decreased, and then the flow rate increases. This is demonstrated when you hold your finger over part of the outlet of a garden hose. Because you decrease the cross sectional area, the water velocity increases. The product Av, which has the dimensions of volume per unit time, is called the flow rate. The condition Av = constant is equivalent to the statement that the volume of fluid that enters one end of a tube in a given time interval equals the volume leaving the other end of the tube in the same time interval if no leaks are present.

$$Flow\,rate = \frac{volume}{time} = Av = constant \quad \text{(3.21)}$$

3.4.1. Bernoulli's Equation

In the 18th century, the Swiss physicists Daniel Bernoulli derived a relationship between the velocity of a fluid and the pressure it exerts. Qualitatively, Bernoulli's principle states that swiftly moving fluids exert less pressure than slowly moving fluids. Bernoulli's principle is extremely important in our everyday life. It is the primary principle which leads to lift on an airplane wing and allows the plane to fly. It is the primary reason a sailboat can sail into the wind. It is the primary reason a baseball can curve. It is an important reason that smoke is drawn up a chimney.

Bernoulli's equation is really a consequence of a fundamental principle of physics: the conservation of energy. It can be derived using energy principles.

Consider a fluid moving through a pipe. The pipe's cross sectional area changes, and the pipe changes elevation. At one point the pipe has a cross sectional area of A_1, a height of y_1, a pressure of P_1, a velocity of v_1 and moves a distance of Δx_1 in a time of Δt. At another point P_1 along the pipe these quantities are given by A_2, y_2, P_2, v_2, and Δx_2.

Conservation of energy gives the following equation, called Bernoulli's equation,

$$P + \frac{1}{2}\rho v^2 + \rho g y = constant \ldots\ldots\ldots\

Unknown:

$$v_2$$
$$P_2$$

Solution:

$$A_1 v_1 = A_2 v_2$$

$$v_2 = \frac{A_1 v_1}{A_2} = \frac{(0.0004\pi \times 0.50 \frac{m}{s})}{1.69 \times 10^{-4}\pi} = 11.83\ m/s$$

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

$$\Longrightarrow P_2 = P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 - \frac{1}{2}\rho v_2^2 - \rho g h_2$$

$$= P_1 + \frac{1}{2}\rho(v_1^2 - v_2^2) + \rho g(h_1 - h_{2)}$$

$$= 3.03 \times 10^5 Pa + \frac{1}{2}(1.0 \times 10^3\ kg/m^3)(0.50^2 - 11.83^2)(m/s)^2 + (1.0 \times 10^3\ kg/m^3)\left(9.80\frac{m}{s^2}\right)(0 - 5.0)m$$

$$= 1.84 \times 10^5 Pa.$$

Chapter Summary

- We can describe the elastic properties of a substance using the concepts of stress and strain. Stress is a quantity proportional to the force producing a deformation; strain is a measure of the degree of deformation. Strain is proportional to stress, and the constant of proportionality is the elastic modulus:

$$Elastic\ modulus = \frac{Stress}{Strain}$$

- Three common types of deformation are represented by (1) the resistance of a solid to elongation under a load, characterized by Young's modulus Y; (2) the resistance of a solid to the motion of internal planes sliding past each other, characterized by the shear modulus S; and (3) the resistance of a solid or fluid to a volume change, characterized by the bulk modulus B.
- The pressure P in a fluid is the force per unit area exerted by the fluid on a surface:

$$P = F/A$$

- In the SI system, pressure has units of Newton's per square meter (N/m^2), and $1\frac{n}{m^2} = 1\ pascal\ (Pa)$
- The pressure in a fluid at rest varies with depth h in the fluid according to the expression:

$$P = P_0 + \rho gh$$

Where P_0 is the pressure at $h = 0$ and ρ is the density of the fluid, assumed uniform.

- Pascal's law states that when pressure is applied to an enclosed fluid, the pressure is transmitted undiminished to every point in the fluid and to every point on the walls of the container.
- When an object is partially or fully submerged in a fluid, the fluid exerts on the object an upward force called the buoyant force. According to Archimedes's principle, the magnitude of the buoyant force is equal to the weight of the fluid displaced by the object:

$$F_b = \rho_f gV$$

- You can understand various aspects of a fluid's dynamics by assuming that the fluid is non-viscous and incompressible, and that the fluid's motion is a steady flow with no rotation.

- Two important concepts regarding ideal fluid flow through a pipe of non-uniform size are as follows:
- The flow rate (volume flux) through the pipe is constant; this is equivalent to stating that the product of the cross-sectional area A and the speed v at any point is a constant. This result is expressed in the equation of continuity for fluids:

$$A_1 v_1 = A_2 v_2 = constant$$

- The sum of the pressure, kinetic energy per unit volume, and gravitational potential energy per unit volume has the same value at all points along a streamline. This result is summarized in Bernoulli's equation:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

Chapter Questions and Problems

1. A 200-kg load is hung on a wire having a length of 4.00 m, cross-sectional area $0.2 \times 10^{-4} m^2$, and Young's modulus $8.0 \times \frac{10^{-10} N}{m^2}$. What is its increase in length?
2. A steel wire of diameter 1 mm can support a tension of 0.2 kN. A cable to support a tension of 20 kN should have diameter of what order of magnitude?
3. A 30.0-kg hammer strikes a steel spike 2.30 cm in diameter while moving with speed 20.0 m/s. The hammer rebounds with speed 10.0 m/s after 0.110 s. What is the average strain in the spike during the impact?
4. If the shear stress in steel exceeds $4.0 \times 10^8 N/m^2$, the steel ruptures. Determine the shearing force necessary to (a) shear a steel bolt 1.00 cm in diameter and (b) punch a 1.00-cm-diameter hole in a steel plate 0.500 cm thick.
5. Lead has a greater density than iron, and both are denser than water. Is the buoyant force on a lead object greater than, less than, or equal to the buoyant force on an iron object of the same volume?
6. When an object is immersed in a liquid at rest, why is the net force on the object in the horizontal direction equal to zero?
7. When water freezes, it expands by about 9.0 %. What pressure increase would occur inside your automobile engine block if the water in it froze? (The bulk modulus of ice is $2.0 \times 10^9\ N/m^2$)
8. A 40-cm tall glass is filled with water to a depth of 30 cm.
    A. What is the gauge pressure at the bottom of the glass?
    B. What is the absolute pressure at the bottom of the glass?
9. Water circulates throughout a house in a hot water heating system. If the water is pumped at a speed of 0.50 m/s through a 4.0-cm diameter pipe in the basement under a pressure of 3.03×10^5 Pa, what will be the velocity and pressure in a 2.6-cm diameter pipe on the second floor 5.0 m above?
10. Calculate the absolute pressure at an ocean depth of 1.0×10^3 m. Assume that the density of the water is 1.025×10^3 kg/m^3 and that $P_{atm} = 1.01 \times 10^5 Pa$.

CHAPTER FOUR

HEAT AND THERMODYNAMICS

Thermodynamics is a science of the relationship between heat, work, temperature, and energy. In broad terms, thermodynamics deals with the transfer of energy from one system to another and from one form to another. In thermodynamics, one usually considers both thermodynamic systems and their environments. A typical thermodynamic system is a definite quantity of gas enclosed in a cylinder with a sliding piston that allows the volume of gas to vary. But in general a thermodynamic system is a quantity of matter of fixed identity that is the subject of study and it may be solid, liquid or gas. The surrounding is the environment that is around a system and in thermal contact with it. In general, a thermodynamic system is defined by its temperature, volume, pressure, and chemical composition. A system is in equilibrium when each of these variables has the same value at all points.

Learning Objectives:

At the end of this chapter, you will be able to:

- State the Zeroth law of thermodynamics and use it to define temperature.
- Distinguish between heat and temperature.
- Convert from one temperature scale to another.
- Explain the concepts of work, heat and internal energy in thermodynamics; determine work and heat sign conventions.
- Define the concepts specific heat and latent heats and solve problems using the concepts.
- Define thermal expansion; distinguish between linear, areal and volume expansions and solve related problems.
- Explain the different heat transfer mechanisms
- Explain the first law of thermodynamics for a closed system and apply it to solve problems.

4.1. The concept of Temperature and the Zeroth law of Thermodynamics

Self Diagnostic Test

1. Can you state the Zeroth law of thermodynamics?
2. How do temperature and heat differ?
3. Can you explain what the first law of thermodynamics says?

Heat is defined as the flow of energy from one object to another. This flow of energy is caused by a difference in temperature. Heat can flow between objects if they are in thermal contact. An important concept related to temperature is thermal equilibrium. Two objects are in thermal equilibrium if they are in close contact that allows either to gain energy from the other, but nevertheless, no net energy is transferred between them. Even when not in contact, they are in thermal equilibrium if, when they are placed in contact, no net energy is transferred between them. If two objects remain in contact for a long time, they typically come to equilibrium. In other words, two objects in thermal equilibrium do not exchange energy.

Experimentally, if object A is in thermal equilibrium with object B, and object B is in thermal equilibrium with object C, then object A is in thermal equilibrium with object C. That statement of transitivity is called the zeroth law of thermodynamics. (The number "zeroth" was suggested by British physicist Ralph Fowler in the 1930s.

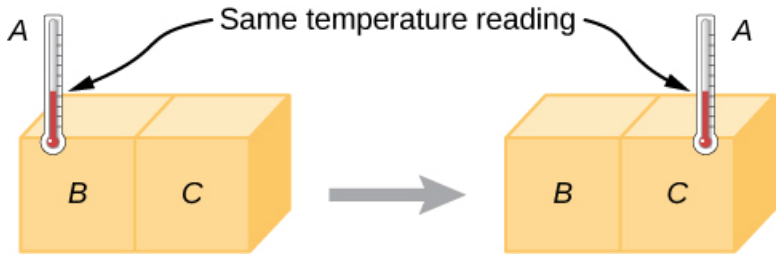


Figure 4.1: If thermometer *A* is in thermal equilibrium with object *B*, and *B* is in thermal equilibrium with *C*, then *A* is in thermal equilibrium with *C*. Therefore, the reading on *A* stays the same when *A* is moved over to make contact with *C*.

The first, second, and third laws of thermodynamics were already named and numbered then. The zeroth law had seldom been stated, but it needs to be discussed before the others, so Fowler gave it a smaller number.) Consider the case where A is a thermometer. The zeroth law tells us that if A reads a certain temperature when in equilibrium with B, and it is then placed in contact with C, it will not exchange energy with C; therefore, its temperature reading will remain the

same (Figure 4.1). In other words, if two objects are in thermal equilibrium, they have the same temperature.

Temperature Scales

Any physical property that depends consistently and reproducibly on temperature can be used as the basis of a thermometer. For example, volume increases with temperature for most substances. This property is the basis for the common alcohol thermometer and the original mercury thermometers. Other properties used to measure temperature include electrical resistance, color, and the emission of infrared radiation.

Thermometers measure temperature according to well-defined scales of measurement. The three most common temperature scales are Fahrenheit, Celsius, and Kelvin. Temperature scales are created by identifying two reproducible temperatures. The freezing and boiling temperatures of water at standard atmospheric pressure are commonly used.

On the Celsius scale, the freezing point of water is 0^0C and the boiling point is 100^0C. The unit of temperature on this scale is the degree Celsius (^{0}C). The Fahrenheit scale has the freezing point of water at 32^0F and the boiling point at 212^0F. Its unit is the degree Fahrenheit (^{0}F).

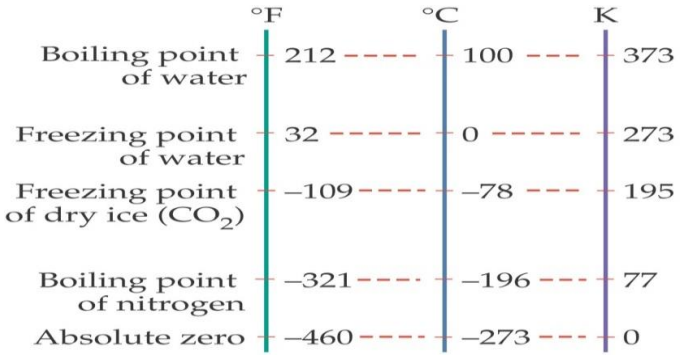


Figure 4.2: Relationships between the Fahrenheit, Celsius, and Kelvin temperature scales are shown. The relative sizes of the scales are also shown.

Activity:

- If the ice-point and the steam-point temperatures on an unknown scale X are 50^0X and 200^0X, respectively, then what is the reading in ^{0}X for a temperature of 60^0C?

Conversions from one temperature scale to the other are possible using the following relations:

Table 4.1 Temperature Conversions

To convert from…	Use this equation…
Celsius to Fahrenheit	$T_F = \frac{9}{5}T_C + 32$
Fahrenheit to Celsius	$T_C = \frac{5}{9}(T_F - 32)$
Celsius to Kelvin	$T_K = T_C + 273.15$
Kelvin to Celsius	$T_C = T_K - 273.15$
Fahrenheit to Kelvin	$T_K = \frac{5}{9}(T_F - 32) + 273.15$
Kelvin to Fahrenheit	$T_F = \frac{9}{5}(T_K - 273.15) + 32$

4.2. Thermal Expansion

The expansion of alcohol in a thermometer is one of many commonly encountered examples of thermal expansion, which is the change in size or volume of a given system as its temperature changes. The most visible example is the expansion of hot air. When air is heated, it expands and becomes less dense than the surrounding air, which then exerts an (upward) force on the hot air and makes steam and smoke rise, hot air balloons float, and so forth.

Linear Thermal Expansion

The increase in length Δl of a solid is proportional to its initial length l_0 and the change in its temperatureΔT.The proportionality constant is called the coefficient of linear expansion, α.

$$\Delta l = \alpha l_0 \Delta T \implies l = l_0(1 + \alpha \Delta T), \quad \alpha = \frac{l_0}{\Delta l}\Delta T \text{ has units } K^{-1} \text{ and } (C^{-0})^{-1}$$

Table 4.2: Some typical coefficients of thermal expansion

Substance	Coefficient of linear expansion, $\alpha(K^{-1})$
Lead	29×10^{-6}
Aluminum	24×10^{-6}
Brass	19×10^{-6}
Copper	17×10^{-6}
Iron (steel)	12×10^{-6}
Concrete	12×10^{-6}
Window glass	11×10^{-6}
Pyrex glass	3.3×10^{-6}
Quartz	0.50×10^{-6}

A bimetallic strip consists of two metals of different coefficients of thermal expansion, A and B in the figure. It will bend when heated or cooled.

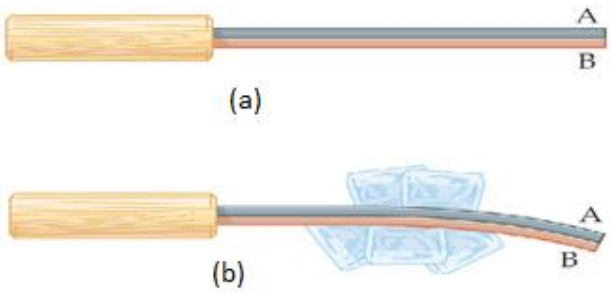


Figure 4.3: The curvature of a bimetallic strip depends on temperature. (a) The strip is straight at the starting temperature, where its two components have the same length. (b) At a higher temperature, this strip bends to the right, because the metal on the left has expanded more than the metal on the right. At a lower temperature, the strip would bend to the left.

Areal Expansion

The change in area ΔA of a solid is proportional to its initial area A_0 and thechange in its temperatureΔT. That is,

$\Delta A = \beta A_0 \Delta T \implies A = A_0(1 + \beta \Delta T)$, where $\beta = 2\alpha$ is the coefficient of areal expansion.

Volume Expansion

The change in volumeΔV of a solid is proportional to its initial volume V_0 and the change in its temperature ΔT. That is:

$\Delta V = \gamma V_0 \Delta T \implies V = V_0(1 + \gamma \Delta T)$, where $\gamma = 3\alpha$ is the coefficient of volume expansion.

Table 4.3: Some typical coefficients of volume expansion

Substance	Coefficient of volume expansion, $\beta (K^{-1})$
Ether	1.51×10^{-3}
Carbon tetrachloride	1.18×10^{-3}
Alcohol	1.01×10^{-3}
Gasoline	0.95×10^{-3}
Olive oil	0.68×10^{-3}
Water	0.21×10^{-3}
Mercury	0.18×10^{-3}

Activity: Metal A has a coefficient of linear expansion that is three times the coefficient of linear expansion of metal B. How does their coefficient of areal expansion, β , compare?

4.3. The Concept of Heat, Work and Internal Energy

Heat, symbol Q and unit Joule (J), is the spontaneous flow of energy into or out of a system caused by a difference in temperature between the system and its surroundings, or between two objects whose temperatures are different. Another aspect of this definition of heat is that a body never contains heat. Rather, heat can be identified only as it crosses the boundary. Thus, heat is a transient phenomenon.

Work, symbol W and unit Joule (J), is a non-spontaneous energy transfer into or out of a system due to force acting through a displacement. Work takes many forms, moving a piston, or stirring, or running an electrical current through a resistance. Work is the non-spontaneous transfer of energy. *Heat and work are two possible ways of transferring energy from one system to another.*

Heat is a microscopic form of energy transfer involving large number of particles; the exchange of energy occurs due to the individual interactions of the particles. No macroscopic displacement occurs when heat flows and no macroscopic force is exerted by one object on the other. A system cannot possess heat or work; these two are energies that flow into or out of a system. Heat transfer obeys the law of conservation of energy (if no heat is lost to the surroundings):

$$\mathbf{Q_{lost\ by\ hotter\ object}} = \mathbf{Q_{gained\ by\ cooler\ object}}$$

Activity: When hot and cold objects are placed in contact, the hot one loses energy. Does this violate energy conservation? Why or why not?

Internal Energy, symbol U, is defined as the energy associated with the random, disordered motion of the microscopic components-atoms and molecules. Any bulk kinetic energy of the system due to its motion through space is not included in its internal energy. Internal energy includes kinetic energy of translation, rotation, and vibration of molecules, potential energy

within molecules, and potential energy between molecules. It is useful to relate internal energy to the temperature of an object, but this relationship is limited, internal energy changes can also occur in the absence of temperature changes.

4.4. Specific Heat and Latent Heat

Specific Heats:

Heat flowing into or out of a body (or system) changes the temperature of the body (or system) except during phase changes the temperature remains constant. The quantity of heat, Q, required to change the temperature of a body of mass m by ΔT is proportional to both the mass and the change in temperature. Mathematically,

$$Q \sim m\Delta T \quad \Longrightarrow \; Q = mc\Delta T$$

c is a proportionality constant called specific heat capacity(or in short specific heat) of the substance defined as the amount of heat required to raise the temperature of a unit mass of any substance through a unit degree. Its SI unit is $J/kg.K$ or $J/kg.^0$C

The amount of heat required to change the temperature of n moles of a substance, usuallyfor gases, by ΔT is :

$$Q = nC\Delta T$$

The heat capacity(C) is defined as the amount of heat energy required to raise the temperature of a substance by 1^0C.

Latent Heats

Latent Heat the heat required per unit mass of a substance to produce a phase change at constant temperature. The latent heat,Q_L, required to change the phase of "m" mass of a body at constant temperature is calculated as,

$$Q_L = \pm \text{mL}$$

Where L is the specific latent heat required to change the phase of 1 kg of a substance at constant temperature.

Table 4.4: Specific Heats of Substances at 25^0C and Atmospheric Pressure

Substance	Specific heat c J/kg · °C	cal/g · °C
Elemental solids		
Aluminum	900	0.215
Beryllium	1 830	0.436
Cadmium	230	0.055
Copper	387	0.092 4
Germanium	322	0.077
Gold	129	0.030 8
Iron	448	0.107
Lead	128	0.030 5
Silicon	703	0.168
Silver	234	0.056
Other solids		
Brass	380	0.092
Glass	837	0.200
Ice (— 5°C)	2 090	0.50
Marble	860	0.21
Wood	1 700	0.41
Liquids		
Alcohol (ethyl)	2 400	0.58
Mercury	140	0.033
Water (15°C)	4 186	1.00
Gas		
Steam (100°C)	2 010	0.48

Types of Latent Heat Transfer

There are two types of latent heat transfers between an object and its environment.

Latent Heat of Fusion (Lf): is the heat absorbed or released when matter melts, changing phase from solid to liquid form at constant temperature. For example, 333.7 kJ of heat is required to change 1 kg of ice to water at 00C, so for water Lf= 333.7kJ/kg.

Latent Heat of Vaporization (L_V): is the heat absorbed or released when matter vaporizes, changing phase from liquid to gas phase at constant temperature. To change 1 kg of water to steam at 100^0C, 2256 kJ of heat is required and so L_V = 2256 kJ.

Example 1:

How much heat energy is required to change a 40 g ice cube from a solid at -10 ^{o}C to steam at 110 ^{o}C?

Table 4.5: This is a table of specific latent heat of fusion and vaporization for common materials.

Substance	Melting Point (°C)	Latent Heat of Fusion (J/kg)	Boiling Point (°C)	Latent Heat of Vaporization (J/kg)
Helium	− 269.65	5.23×10^3	− 268.93	2.09×10^4
Nitrogen	− 209.97	2.55×10^4	− 195.81	2.01×10^5
Oxygen	− 218.79	1.38×10^4	− 182.97	2.13×10^5
Ethyl alcohol	− 114	1.04×10^5	78	8.54×10^5
Water	0.00	3.33×10^5	100.00	2.26×10^6
Sulfur	119	3.81×10^4	444.60	3.26×10^5
Lead	327.3	2.45×10^4	1 750	8.70×10^5
Aluminum	660	3.97×10^5	2 450	1.14×10^7
Silver	960.80	8.82×10^4	2 193	2.33×10^6
Gold	1 063.00	6.44×10^4	2 660	1.58×10^6
Copper	1 083	1.34×10^5	1 187	5.06×10^6

Solution:

To raise the temperature of the ice to ℃ we need,

$$\Delta Q_{ice} = m_{ice} c_{ice} \Delta T = 0.04 \text{ kg} \left(0.49 \frac{\text{kcal}}{\text{kg} \,.\, ℃}\right) 10 ℃ = 0.196 \text{ kcal.}$$

To melt the ice we need,

$\Delta Q_{ice} = m_{ice} L_{ice}$ =0.04 kg (80 kcal/kg) = 3.2 kcal.

To raise the temperature of the water to 100 ^{o}C we need,

$$\Delta Q_{water} = m_{water} c_{water} \Delta T = 0.04 \text{ kg} \left(1 \frac{\text{kcal}}{\text{kg} ℃}\right) 100 ℃ = 4 \text{ kcal.}$$

To boil the water we need,

$$\Delta Q_L = m_{water} L_{iwater} = 0.04 \text{ kg} \left(540 \text{ k} \frac{\text{cal}}{\text{kg}}\right) = 21.6 \text{ kcal}$$

To raise the temperature of the steam to 110^{o}C we need,

$$\Delta Q_{ice} = m_{steam} c_{steam} \Delta T = 0.04 \text{kg} (0.48 \text{ kcal}/(\text{kg}℃)) 10℃ = 0.192 \text{ kcal.}$$

Therefore, the total heat energy required is

ΔQ =(0.196 + 3.2 + 4 + 21.6 + 0.192)kcal = 29.188 kcal.

Example 2:

If 90 g of molten lead at 327.3 ^{0}C is poured into a 300 g casting form made of iron and initially at 20.0^{0}C, what is the final temperature of the system? Assume no energy is lost to the environment.

Solution:

The melting point of lead is 327.3^{0}C.Assume the final temperature of the system is T,

- the amount of energy released bythe lead as it solidifies is $\Delta Q_L = m_{lead} L_{lead} = 0.09\ \text{kg}(2.45 \times 104\ \text{J/kg}) = 2205\ \text{J}$, and
- the amount of energy released as it cools is

$\Delta Q = m_{lead} c_{lead} \Delta T = 0.09\ (128\ )(327.3 - \text{T}) = (11.52)(327.3 - \text{T})$
This energy is absorbed by the iron. For the iron we therefore have

$$2205 + (11.52)\,(327.3 - \text{T}) = m_{iron} c_{iron} \Delta T = 0.3\ (448)(\text{T} - 20)$$

$$5975.5 - (11.52)\text{T} = 134\,\text{T} - 2688$$

$$8663.5 = (145.52\ )\text{T}$$

$$\text{T} = 59.5^0 C$$

Activity: A liquid of unknown specific heat at a temperature of 20^{o}C was mixed with water at 80^{o}C in a well-insulated container. The final temperature was measured to be 50^{o}C, and the combined mass of the two liquids was measured to be 240g. In a second experiment with both liquids at the same initial temperatures, 20 g less of the liquid of unknown specific heat was poured into the same amount of water as before. This time the equilibrium temperature was found to be 52^{o}C. Determine the specific heat of the liquid. The specific heat of water is 4187 J/Kg^{o}C or 1 kcal/kg^{o}C.

4.5. Heat Transfer Mechanisms

Heat may be transferred from one place to another in three ways:

- conduction
- convection
- radiation
- direct burning

Often a combination of all four processes takes place at the same time, especially in a fire situation. If we wish to contain heat, then these processes must be prevented.

Conduction

Conduction is most obvious in solids. All liquids (except mercury) and gases are very poor conductors of heat. When a solid heats up, its particles gain kinetic energy and increase the energy with which they vibrate. Conduction occurs when heat energy travels through a body, passing from particle to particle as they vibrate against each other. A good conductor must have particles which are close enough together to collide with sufficient force for energy to be transferred. Metals are all good conductors of heat especially copper, aluminum and silver, because they have "free" electrons which are easily able to transfer heat energy.

Activity: Explain how fire may spread by conduction in a building from one room to the other and suggest the ways to prevent its spread.

Fire spread by conduction of heat may occur in a building along the metal beams supporting the building. Metal doors or door handles subject to heat on one side rapidly conduct heat to the other side. The presence of an insulator (poor conductor) may trap heat and cause heat build –up until ignition temperature is reached, e.g. faulty electric blankets under eiderdowns or pillows.

Convection

Convection is the transfer of heat by the movement of the heated particles themselves. This can only take place in liquids and gases because in solids the particles are not able to move from their fixed positions. When a liquid or gas is heated, it expands and becomes less dense. The lighter liquid or gas rises allowing a flow of cooler material to take its place. This in turn becomes heated and so a current is set up. Heat will continue to be transferred through the available space in this way until it is evenly distributed.

In a fire situation, convection currents can carry hot gases and burning fragments up through stairwells and open lift shafts, spreading fire to the upper parts of a building. A current of cool air replaces the hot gases, providing a continuous supply of oxygen for the fire.

Activity: A vacuum flask (sometimes called a Thermos bottle) is a double-wall container with a vacuum between the two walls. How does the flask keep its contents hotter than the

A vacuum is an extremely poor conductor of heat. Placing a vacuum between the two walls keeps the contents hotter than outside air because the presence of the vacuum limits the transfer of heat. Heat will ultimately be transferred slowly through the cap (for example), but will keep the substance much hotter than another type of container.

Radiation

Radiation is the way we receive heat energy from the sun. It does not require a medium for its transmission (i.e. it can travel through empty space) and is in the form of electromagnetic energy waves which travel in the same way as light or radio waves. When these energy waves fall on a body, the energy may be:

- absorbed
- transmitted
- reflected

When radiant energy is absorbed the body will rise in temperature. A rack of clothes left in front of a radiant heater will continue to absorb heat until it reaches ignition temperature. Black and dull surfaces absorb (and radiate) heat much more efficiently than white shiny surface The amount of heat energy received decreases with the square of the distance from a radiant source, for example, if an object is moved to twice the distance from a source, it will only receive a quarter of the heat energy it would have received at the original distance.

Radiant energy is transmitted through clear materials such as glass. The glass does not heat up. Radiant heat from the sun may be concentrated by means of a magnifying glass, sufficient to ignite flammable material. Shiny, silver surfaces will reflect radiant energy and not heat up. This is the reason for the silver coating on a fire-fighter's jacket.

Direct Burning

Some agencies use the term 'direct burning' to describe how physical contact of the flame with other available fuel spreads a fire. By this form of direct fire spread, the heat of a fire will

transfer across any area where there is a line of fuel for the fire to follow. Some examples of direct burning are:

• Fire spreading along a piece of wood and setting fire to other pieces of wood in contact with it.

Activity: Water is very effective as an extinguishing agent because of its cooling effect. Why is this so? Would other liquids have the same cooling effect?

Water as an Extinguishing Agent

When sand and water are exposed to the same amount of heat energy from the sun, you will have observed that sand gets much "hotter" (attains a higher temperature) than water. This is because water has a much higher specific heat than sand. This means that for each degree temperature rise it will absorb a greater amount of heat than sand. The "specific heat" of a substance measures the amount of heat absorbed by 1 kilogram of the substance when it's temperature is raised by 1^{o}C.

4.6. The First Law of Thermodynamics

The first law of thermodynamics states that: "*The change in internal energy of a system is equal to the sum of the heat flow into the system and the work done on the system.*"

In equation form the first law can be written as

$$\Delta U = Q + W$$

Where ΔU is the change in internal energy of the system, W= PΔV is the work done on the system (or by the system) and P and ΔV are the pressure and change in volume of the system.

The first law is a specialized statement of energy conservation applied to a thermodynamic system, such as a gas inside a cylinder that has a movable piston. The gas can exchange heat with its surroundings in two ways. Heat can flow between the gas and its surroundings when they are at different temperatures and work can be done on the gas when the piston is pushed in.

The First Law for different thermodynamic systems:

Isolated system-is a system which does not exchange heat with its surrounding and no work is done on the external environment. In this case Q=0 and W=0, so from the first law we conclude $\Delta U = 0 \; or \; U = constant$

The internal energy of an isolated system is constant.

Cyclic Process

Engines operate in cycles, in which the system –for example, a gas-periodically returns to its initial state. Since the system returns to its initial state, the change in internal energy in one complete cycle is zero; that is, $\Delta U = 0$. From the first law we see that

$$Q = W$$

Isochoric process

In a constant volume process, the volume of the system stays constant. Consequently, W=0. From the first law we see that

$$\Delta U = Q$$

All the heat entering the system goes into increasing the internal energy.

Adiabatic Process

In an adiabatic process, the system does not exchange heat with its surroundings; that is, Q = 0. The first law for an adiabatic process takes the form

$$\Delta U = W$$

Isothermal Process

It is a process which involves no change in the temperature of the system. If the process occurs at constant temperature then there is no change in the internal energy of the system so ΔU. The first law for an isothermal process takes the form

$$\Delta \mathrm{U} = \mathrm{Q} + \mathrm{W}$$

$$0 = \mathrm{Q} + \mathrm{W}$$

$$\mathrm{Q} = -\mathrm{W}$$

For an ideal gas in isothermal process the work done is calculated as

$$\mathrm{W} = \mathrm{nRT} \ln(\frac{\mathrm{V_f}}{\mathrm{V_i}})$$

Isobaric process

In an isobaric process the expansion or compression occurs at constant pressure. Any work done by the system will result in an increase in volume. The work done in Pressure- Volume graph is equal to the area under the PV graph. For an isobaric process the work done W is calculated as

$$W = P\Delta V = P\,(V_f - V_i)$$

The first law for an isobaric process can be written as

$$\Delta U = Q + W \text{ or } \Delta U = Q - P\Delta V = Q - P\,(V_f - V_i)$$

Example 1:

5000 J of heat are added to two moles of an ideal monatomic gas, initially at a temperature of500 K, while the gas performs 7500 J of work. What is the final temperature of the gas?
Solution

$$\Delta U = Q + W = 5000\text{J} - 7500\text{J} = -2500\text{J}$$

From the equation, $\Delta U = nC\Delta T$

$$-2500 = \frac{3}{2}nR\Delta T = \left(\frac{3}{2}\right)(2)(8.31) = \Delta T$$

$$\Delta T = -100\ K$$

$$T_f - 500K = -100\ K$$

$$\Rightarrow T_f = 400\ K$$

The gas does more work than it takes in as heat .So, it must use 2500 J of its internal energy.

Example 2:

2000 J of heat leaves the system and 2500 J of work is done on the system. What is the change in internal energy of the system?

Solution :

$\Delta U = Q + W$

$\Delta U = -2000 + 3000$

$\Delta U = 1000$ Joule

Therefore, internal energy increases by 4500 Joule.

Activity: A 1.0 mol sample of an ideal gas is kept at 0.0°C during an expansion from 3.0 L to 10.0 L.
a) How much work is done on the gas during the expansion?
b) How much energy transfer by heat occurs with the surroundings in this process?

Chapter Summery

- Two objects are in thermal equilibrium with each other if they do not exchange energy when in thermal contact.
- The zeroth law of thermodynamics states that if objects A and B are separately in thermal equilibrium with a third object C, then objects A and B are in thermal equilibrium with each other.
- Temperature is the property that determines whether an object is in thermal equilibrium with other objects. Two objects in thermal equilibrium with each other area the same temperature. T he SI unit of absolute temperature is the Kelvin, which is defined to be the fraction 1/273.16 of the temperature of the triple point of water.
- When the temperature of an object is changed by an amount ΔT, its lengthchanges by an amount Δlthat is proportional to $\Delta T$and to its initial length l_0:

$$\Delta l = \alpha l_0 \Delta T$$

  Where, the constant α is the average coefficient of linear expansion. The average coefficient of areal and volume expansions respectively are $\beta = 2\alpha$ and $\gamma = 3\alpha$.
- Internal energy is all of a system's energy that is associated with the system's microscopic components. Internal energy includes kinetic energy of random translation, rotation, and vibration of molecules, potential energy within molecules, and potential energy between molecules.
- Heat is the transfer of energy across the boundary of a system resulting from a temperature difference between the system and its surroundings. We use the symbol Q for the amount of energy transferred by this process.
- The heat capacity C of any sample is the amount of energy needed to raise the temperature of the sample by 1°C.
- The energy Q required to change the temperature of a mass m of a substance by an amount $\Delta T$is$Q = mc\Delta T$, where c is the specific heat of the substance.
- The energy required to change the phase of a pure substance of mass m is $Q = \pm mL$, where L is the latent heat of the substance and depends on the nature of the phase change and the

properties of the substance. The positive sign is used if energy is entering the system, and the negative sign is used if energy is leaving.

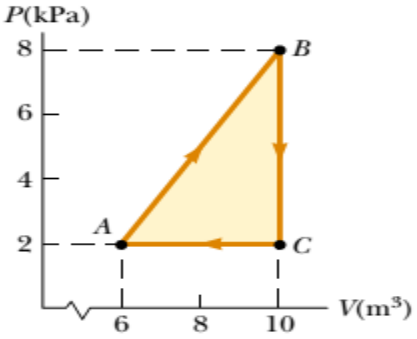
- The first law of thermodynamics states that when a system undergoes a change from one state to another, the change in its internal energy is $\Delta U = Q + W$,

  where Q is the energy transferred into the system by heat and W is the work done on the system. Although Q and W both depend on the path taken from the initial state to the final state, the quantity ΔU is path-independent.
- In a **cyclic process** (one that originates and terminates at the same state),$\Delta U = 0$ and, therefore, $Q + W = 0 \implies Q = -W$. That is, the energy transferred into the system by heat equals the negative of the work done on the system during the process.
- In an **adiabatic process**, no energy is transferred by heat between the system and its surroundings ($Q = 0$). In this case, the first law gives $\Delta U = W$. That is, the internal energy changes as a consequence of work being done on the system. In the adiabatic free expansion of a gas $Q = 0$and $W = 0$, and so $\Delta U = 0$. That is, the internalenergy of the gas does not change in such a process.
- An **isobaric process** is one that occurs at constant pressure. The work done on a gas in such a process is $W = -P(V_f - V_i)$.
- An **isovolumetric process** is one that occurs at constant volume. No work is done in such a process, so $\Delta U = Q$.An isothermal process is one that occurs at constant temperature. The work done on an ideal gas during an isothermal process is$W = nRT \ \ln(V_i/V_f)$.

Review Questions and Problems

1. Clearly distinguish among temperature, heat, and internal energy.
2. What is wrong with the following statement? “Given any two objects, the one with the higher temperature contains more heat.”
1. The temperature of a silver bar rises by 10°C when it absorbs 1.23kJ of energy by heat. The mass of the bar is 525g. Determine the specific heat of silver.
2. Calculate the quantity of heat required to raise the temperature of 1 g of ice from -10^0C to 110^0C.
3. If 20 g steam initially at 100^0C is added to 60 g of ice initially at 0^0C, then find the final equilibrium temperature of the mixture.
4. The temperature of a silver bar rises by 10.0°C when it absorbs1.23 kJ of energy by heat. The mass of the bar is525 g. Determine the specific heat of silver.
5. A 50.0-g sample of copper is at 25.0°C. If 1 200 J of energy is added to it by heat, what is the final temperature of the copper?
6. A system absorbs 35J of heat and in the process it does 11J of work. (a) If the initial internal energy is 205J what is the final internal energy? (b) The system follows a different thermodynamic path to the same final state and does 15J of work, what is the heat transferred?
7. A gas is compressed at a constant pressure of 0.800atm from 9.00 L to 2.00 L. In the process, 400 J of energy leaves the gas by heat. (a) What is the work done on the gas? (b) What is the change in its internal energy?
8. A gas is confined to a vertical cylinder by a piston of mass 2 kg and radius 1 cm. When 5J of heat are added, the piston rises by 2.4 cm. Find: (a) the work done by the gas; (b) the change in its internal energy. Atmospheric pressure is 10^5Pa.
9. A thermodynamic system undergoes a process in which its internal energy decreases by 500 J. At the same time, 220 J of work is done on the system. Find the energy transferred to or from it by heat.
10. A gas is compressed at a constant pressure of 0.8atm from 9.00L to 2.0 L. In the process, 400J of energy leaves the gas by heat. (a) What is the work done on the gas? (b) What is the change in its internal energy?

11. A gas is taken through the cyclic process described in Figure 1. (a) Find the net energy transferred to the system by heat during one complete cycle. (b) If the cycle is reversed-that is, the process follows the path ACBA-what is the net energy input per cycle by heat?



CHAPTER FIVE

OSCILLATIONS, WAVES AND OPTICS

Waves are responsible for basically every form of communication we use. Whether you're talking out loud, texting on your phone or waving to someone in a crowd there's going to be a wave transmitting information. An oscillation is a disturbance in a physical system that is repetitive in time. A wave is a disturbance in an extended physical system that is both repetitive in time and periodic in space. In general, an oscillation involves a continuous back and forth flow of energy between two different energy types: e.g., kinetic and potential energy, in the case of a pendulum. A wave involves similar repetitive energy flows to an oscillation, but, in addition, is capable of transmitting energy and information from place to place. Now, although sound waves and electromagnetic waves, for example, rely on quite distinct physical mechanisms, they, nevertheless, share many common properties. The same is true of different types of oscillation. It turns out that the common factor linking various types of wave is that they are all described by the same mathematical equations. Again, the same is true of various types of oscillation.

Learning objectives: At the end of this chapter, you will be able to:

- Discuss systems that oscillate with simple harmonic motion.
- Explain the concept of wave,
- Describe the wave motion and derive the wave equation
- State Doppler Effect

5.1. Simple Harmonic Motion

Self Diagnostic Test

- What is oscillation in waves?
- What is difference between wave and oscillation?
- What is difference between vibration and oscillation?
- Why are vibrations important? (in both science and engineering)

5.1.1. Periodic and Oscillatory Motion

When a body repeats its path of motion back and forth about the equilibrium or mean position, the motion is said to be periodic. All periodic motions need not be back and forth like the motion of the earth about the sun, which is periodic but not vibratory in nature. The periodic motion in which there is existence of a restoring force and the body moves along the same path to and fro about a definite point, equilibrium position, is called oscillatory motion. In all types of oscillatory motion one thing is common that is each body (performing oscillatory motion) is subjected to a restoring force that increases with increase in displacement from mean position.

Types of oscillatory motion:

There are two types of oscillatory motion: *linear oscillation* and *circular oscillation.*

Example of *linear oscillation*:-

1. Oscillation of mass spring system.
2. Oscillation of fluid column in a U-tube.
3. Oscillation of floating cylinder.
4. Oscillation of body dropped in a tunnel along earth diameter.
5. Oscillation of strings of musical instruments.

Example of circular oscillation:-

1. Oscillation of simple pendulum.
2. Oscillation of solid sphere in a cylinder (If solid sphere rolls without slipping).
3. Oscillation of a circular ring suspended on a nail.
4. Oscillation of balance wheel of a clock.
5. Rotation of the earth around the sun.

Oscillatory system:

Oscillators are the basic building blocks of waves. Oscillatory systems are of two types, *mechanical* and *non- mechanical systems*.

Mechanical oscillatory system: In this type of system a body itself changes its position. For mechanical oscillation two things are especially responsible, *inertia* and *restoring force*.

Non-mechanical oscillatory system: In this type of system, the body itself doesn't change its position but its physical property varies periodically.

PERIOD (T): is the time required to complete one full cycle of vibration or oscillation.

FREQUENCY (*f*): The frequency is the number of complete oscillations or cycles per unit time. The frequency of wave is given by:

$$f = \frac{1}{T} \quad \text{.....(5.1.1)}$$

Example:

On average a human heart is found to beat 75 times in a minute. Calculate its frequency and period.

Solution:

The beat frequency of heart = 75/1min = 75/60sec = 1.25/sec = 1.25Hz

The time period T = 1/1.25se-1 = 0.8sec

AMPLITUDE (A): is the maximum displacement of the oscillator from the equilibrium position.

Simple harmonic motion is a special type of oscillatory motion caused by a restoring force which obeys Hooke's law. In SHM acceleration (a) is always directly proportional in size but opposite in direction to its displacement (x).

A block, of mass m, attached to one end of a spring, of constant k, and oscillating in a horizontal frictionless floor (Figure 5.1) is one example of a SHM.

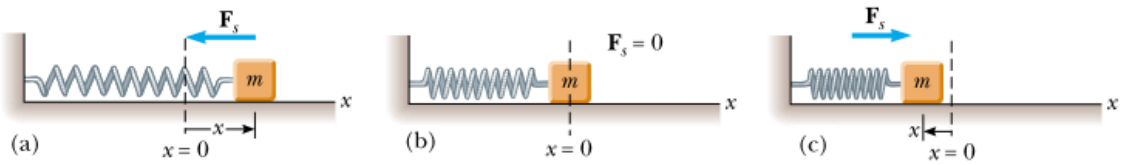


Figure 5.1: A block attached to a spring moving on a frictionless surface. a) When the block is displaced to the right of equilibrium (x>0), the force exerted by the spring acts to the left, b) When the block is at its equilibrium position (x<0), the force exerted by the spring is zero, c) When the block is displaced to the left of equilibrium (x<0), the force exerted by the spring acts to the right.

Assuming the net force on the block is the spring force which obeys Hooke's law:

$$F_s = -kx \quad \text{.....(5.1.2)}$$

The minus sign shows the force is always acting opposite to the displacement and always tries to restore the block back to its equilibrium position. Newton's 2nd law, $F_s = ma$, applied to the block gives:

$$ma = -kx \Rightarrow a = -(\frac{k}{m})x = -\omega^2 x \quad \text{.....(5.1.3)}$$

Where k is the constant of proportionality called the spring constant or stiffness factor and ω is the angular frequency of the oscillator.

Not all periodic motions over the same path can be classified as simple harmonic motion. A ball being tossed back and forth between a parent and a child moves repetitively, but the motion isn't simple harmonic motion because the force acting on the ball doesn't take the form of Hooke's law.

Characteristics of SHM:

1. The amplitude A is constant.
2. The frequency and period are independent of the amplitude.
3. The fluctuating quantity can be expressed in terms of sinusoidal function of a single frequency.

For SHM to occur,

- there must be a stable equilibrium position
- there must be no dissipation of energy
- the acceleration is proportional to the displacement and opposite in direction.

5.1.2. Displacement, Velocity and Acceleration in a SHM

Displacement: $x = A\sin(\omega t)$; (if the oscillator starts from the equilibrium position)……(5.1.4)

Velocity: $V = \omega A\cos(\omega t)$ …….(5.1.5)

Acceleration: $a = -\omega^2 A\sin(\omega t) = -\omega^2 x$

- *Maximum velocity* occurs at equilibrium position with $v_{max} = \omega$ A…….(5.1.6)
- *Maximum acceleration* is observed at $x = \pm A$; $a_{max} = \omega^2 A$……..(5.1.7)

Example*:*

An object oscillates with simple harmonic motion along the *x* axis. Its position varies with time according to the equation $x = (4.00)m\cos(\pi t + \frac{\pi}{4})$ where t is in seconds and the angles in the parentheses are in radians.

a) Determine the amplitude, frequency, and period of the motion.
b) Calculate the velocity and acceleration of the object at any time *t*.
c) Using the results of part (b), determine the position, velocity, and acceleration of the object at t = 1.00 s.
d) Determine the maximum speed and maximum acceleration of the object.

Solution

Comparing the given equation $x = (4.00)m\cos(\pi t + \frac{\pi}{4})$ *with the general equation for simple harmonic motion* $x(t) = A\cos(\omega t + \Phi)$*:*

a) $A = 4m, \qquad \omega = \frac{\pi rad}{s} \rightarrow f = \frac{\omega}{2\pi} = \frac{\frac{\pi rad}{s}}{2\pi} = 0.5Hz, \qquad T = \frac{1}{f} = \frac{1}{0.5Hz} = 2s$

b) $vv = \frac{dx}{dt} = \frac{d[(4.00)m\cos\left(\pi t + \frac{\pi}{4}\right)]}{dt} = -(4\pi)m/s\sin\left(\pi t + \frac{\pi}{4}\right)$

$a = -(4\pi)^2 m/s^2\cos(\pi t + \frac{\pi}{4})$

c) $x(t) = (4.00)m\cos(\pi t + \frac{\pi}{4})$

$$x(t = 1s) = (4.00)m\cos\left(\pi(1s) + \frac{\pi}{4}\right) = -2.83$$

$$v(t) = -(4\pi)m/s\sin\left(\pi t + \frac{\pi}{4}\right)$$

$$v(t = 1s) = -(4\pi)m/s\sin\left(\pi(1s) + \frac{\pi}{4}\right) = 8.89m/s$$

$$a(t) = -(4\pi^2)m/s^2\cos\left(\pi t + \frac{\pi}{4}\right)$$

$$a(t = 1s) = -(4\pi^2)m/s^2\cos\left(\pi(1s) + \frac{\pi}{4}\right) = 27.9m/s^2$$

d) $v_{max} = \omega A = \pi rad/s(4m) = 12.56m/s$

$$a_{max} = \omega^2 A = \left(\frac{\pi rad}{s}\right)^2 (4m) = 39.4m/s^2$$

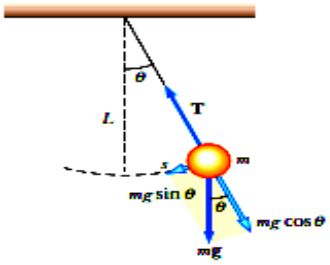
Activity:

For a simple harmonic oscillator, which of the following pairs of vector quantities can't both point in the same direction? (The position vector is the displacement from equilibrium.)

5.2. The simple Pendulum

A simple pendulum is another mechanical system that exhibits periodic motion. It consists of a small bob of mass *m* suspended by a light string of length *L* fixed at its upper end, as in Figure 5.2. (By a light string, we mean that the string's mass is assumed to be very small compared with the mass of the bob and hence can be ignored.) When released, the bob swings to and fro over the same path, so that its motion is simple harmonic.

Figure 5.2: the simple pendulum



The force of gravity is the only force that acts on the pendulum. The pendulum bob moves along a circular arc, rather than back and forth in a straight line. When the oscillations are small, however, the motion of the bob is nearly straight, so Hooke's law may apply approximately.

$$T = 2\pi\sqrt{\frac{L}{g}} \quad \text{.....(5.2.1)}$$

This equation reveals somewhat surprising result that the period of a simple pendulum doesn't depend on the mass, but only on the pendulum's length and on the free-fall acceleration. Further, the amplitude of the motion isn't a factor as long as it's relatively small.

Geophysicists often make use of the simple pendulum and equation 5.2.1 when prospecting for oil or minerals. Deposits beneath the Earth's surface can produce irregularities in the free-fall acceleration over the region being studied. A specially designed pendulum of known length is used to measure the period, which in turn is used to calculate *g*. Although such a measurement in itself is inconclusive, it's an important tool for geological surveys.

Example:

A rock swings in a circle at constant speed on the end on a string, making 50 revolutions in 30sec. What is the frequency and the period for this motion?

Solution

f = 50rev/30sec = 1.67rev/sec = 1.67 Hz

T = 1/f = 1/0.5Hz = 2sec

Activity*:*

A butcher throws a cut of beef on spring scales which oscillates about the equilibrium position with a period of T = 0.500 s. The amplitude of the vibration is A = 2.00 cm (path length 4.00 cm). Find: a) frequency, b) the maximum acceleration, c) the maximum velocity

Energy of the Simple Harmonic Oscillator

In the absence of friction, the total energy of a block-spring system is constant and equal to the sum of the kinetic and potential energies.

The *potential energy* is given by: $PE = \frac{1}{2}kx^2$ .....(5.2.2)

The *kinetic energy* is also given by: $KE = \frac{1}{2}mv^2$ ……(5.2.3)

Therefore the *total energy* of the oscillator performing SHM is: $E = \frac{1}{2}kA^2$ ……..(5.2.4)

Energy of SHM is constant and proportional to the square of amplitude.

5.3. Wave and Its Characteristics

Self Diagnostic Test

What is a Wave?

The world is full of waves. Sound waves, waves on a string, seismic waves, and electromagnetic waves, are some of examples of a wave. When you drop a pebble into a pool of water, the disturbance produces water waves, which move away from the point where the pebble entered the water. A leaf floating near the disturbance moves up and down and back and forth about its original position, but doesn't undergo any net displacement attributable to the disturbance. This means that the water wave (or disturbance) moves from one place to another, but the water isn't carried with it.

All waves carry energy and momentum. The amount of energy transmitted through a medium and the mechanism responsible for the transport of energy differ from case to case. The energy carried by ocean waves during a storm, for example, is much greater than the energy carried by a sound wave generated by a single human voice.

Wave is a disturbance from normal or equilibrium condition that travels, or propagates, carrying energy and momentum through space without the transport of matter.

Pulse is a single disturbance traveling into a medium. Wave supplies energy to the particles in a medium to set them in to motion.

Terminologies in Wave

Crests/Troughs: are positions in a wave with maximum displacements above/below the equilibrium position.

Amplitude (A): is the maximum displacement from the equilibrium position.

Displacement (y): is position of a wave from equilibrium position at any time.

Wave length (λ): distance between any two consecutive points which are in phase.

Period (T): is the time taken by a wave to move one wave length.

Frequency (*f*): number of oscillations performed per unit time.

Speed (v): is constant in a medium provided the medium is homogeneous.

$$v = \lambda f \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.3.1)$$

Types of waves

Waves can be categorized as Mechanical and Electromagnetic waves based on the need of material medium for its propagation.

1) **Mechanical Waves** - are waves produced by the oscillation of particles of a mechanical medium and need a medium for propagation. Examples are water waves, sound wave, waves in strings etc.

All mechanical waves require:

- ✓ some source of disturbance
- ✓ a medium that can be disturbed and
- ✓ physical medium through which elements of the medium can influence each other.

2) **Electromagnetic (EM) waves**-are produced by accelerated charged particles and can propagate through both material medium and vacuum. Examples are: Light, radio and television waves, micro waves, x-rays, etc. All EM waves in vacuum propagate with speed $c = 3.0 \times 10^8$m/s.

Waves can either move in space (e.g water waves), the so called traveling waves, or be stationary in an enclosure, the so called standing waves.

Waves can also be categorized as transverse and longitudinal waves based on the way they are propagating.

1) **Transverse Wave**- is a wave where particles of the disturbed medium oscillate perpendicular to the direction of wave motion. Examples are: water waves, waves on strings, and all EM waves. Sinusoidal graphs can represent this motion.
2) **Longitudinal Wave**- is a wave where particles of the disturbed medium oscillate parallel to the direction of wave motion. Example: sound wave

5.4. Resonance

Resonance is the increase in amplitude of oscillation of an electric or mechanical system exposed to a periodic force whose frequency is equal or very close to the natural undamped frequency of the system.

Resonance is a phenomenon in which an external force or a vibrating system forces another system around it to vibrate with greater amplitude at a specified frequency of operation. The frequency at which the second body starts oscillating or vibrating at higher amplitude is called the resonant frequency of the body. The best examples of resonance can be observed in various musical instruments around us.

A classic example of resonance is the swinging of a person sitting on a swing. A swing is a very good example of an object in oscillating motion. Initially, the motion is slow and the swing doesn't extend to its maximum potential. But once when the swing reaches its natural frequency of oscillation, a gentle push to the swing helps it maintain that amplitude of swing all throughout due to resonance.

In an ideal situation, with no friction at all, even that slight push won't be necessary once the swing reaches its natural frequency for it to sustain the maximum amplitude forever. Also almost all musical instruments, like the flute, guitar etc work on the principle of resonance itself.

5.5. The Doppler Effect

The Doppler Effect is observed whenever the source of waves is moving with respect to an observer. It can be described as the effect produced by a moving source of waves in which there is an apparent upward shift in frequency for observers towards whom the source is approaching and an apparent downward shift in frequency for observers from whom the source is receding. It

is important to note that the effect does not result because of an actual change in the frequency of the source.

The Doppler Effect can be observed for any type of wave; water wave, sound wave, light wave, etc. We are most familiar with the Doppler Effect because of our experiences with sound waves. For instance a police car or emergency vehicle traveling towards a listener on the highway with its siren blasting, the pitch of the siren sound (a measure of the siren's frequency) will be high; and then suddenly after the car passed by, the pitch of the siren sound gets low.

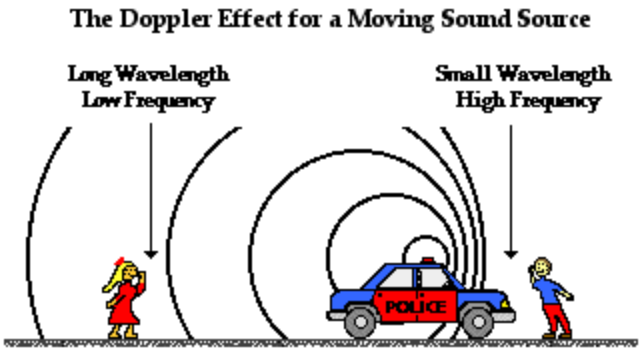


Figure 5.3: a police car receding from a girl and approaching to a boy. The wavelength of a wave gets longer when preceding and shorter when approaching.

Let*:* f_o = frequency heard by the observer and f_s = frequency emitted by the source.

Let: v_o, v, and v_s respectively be velocities of the observer, sound wave and the source.

The observed frequency due to Doppler Effect is:

$$f_o = f_s\left(\frac{v \pm v_o}{v \mp v_s}\right)$$

- "Upper" signs (i.e., + v_o and − v_s) refer to motion of one towards the other.
- "Lower" signs (i.e., −v_o and + v_s) refer to motion of one away from the other.

Characteristics of Waves

The characteristics of waves are important in determining the size of waves, the speed at which they travel, how they break on shore, and much more. Following are some of the characteristics of waves.

Reflection of Waves

Whenever a traveling wave reaches a boundary, part or all of the wave bounces back. This phenomenon (rebounding of wave from a surface) is called reflection. For example, consider a pulse traveling on a string that is fixed at one end. When the pulse reaches the wall, it is reflected.

Refraction of wave

It is the change in direction of a wave passing from one medium to another caused by its change in speed. For example, waves in deep water travel faster than in shallow. If an ocean wave approaches a beach obliquely, the part of the wave farther from the beach will move faster than that closer in, and so the wave will swing around until it moves in a direction perpendicular to the shoreline. The speed of sound waves is greater in warm air than in cold. At night, air is cooled at the surface of a lake, and any sound that travels upward is refracted down by the higher layers of air that still remain warm. Thus, sounds, such as voices and music, can be heard much farther across water at night than in the daytime.

Diffraction of wave

It is the spreading of waves around obstacles. Diffraction takes place with sound; with electromagnetic radiation, such as light, X-rays, and gamma rays; and with very small moving particles such as atoms, neutrons, and electrons, which show wavelike properties. One consequence of diffraction is that sharp shadows are not produced. The phenomenon is the result of interference (i.e., when waves are superimposed, they may reinforce or cancel each other out) and is most pronounced when the wavelength of the radiation is comparable to the linear dimensions of the obstacle.

Interference of wave

It is the net effect of the combination of two or more wave trains moving on intersecting or coincident paths. The effect is that of the addition of the amplitudes of the individual waves at each point affected by more than one wave.

Interference also occurs between two wave trains moving in the same direction but having different wavelengths or frequencies. The resultant effect is a complex wave. A pulsating frequency, called a beat, results when the wavelengths are slightly different.

Activities:

1. Can you mention the types of interference and explain their difference?
2. Draw the diagrams illustrating the different characteristics of wave.

5.6. Image Formation by Thin Lenses and Mirrors

Self Diagnostic Test

1. Can you mention some of the applications of image formation in your daily life experience?
2. What is image from physics point of view?
3. How is image formed in mirrors and lenses?
4. List at least five devices in which the application of image is used?

5.6.1. Images Formed by plane Mirrors

If the reflecting surface of the mirror is flat then we call this type of mirror as ***plane mirror***. Light always has regular reflection on plane mirrors. Given picture below shows how we can find the image of a point in plane mirrors.

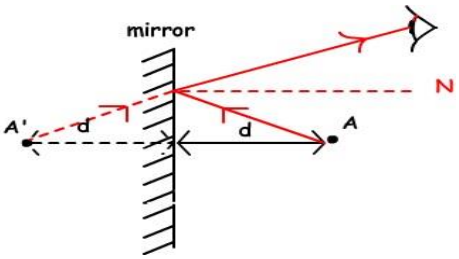


Figure 5.4: image formed by a plane mirror

We have to see the rays coming from the object to see it. If the light first hits the mirror and then reflects with the same angle, the extensions of the reflected rays are focused at one point behind

the mirror. We see the coming rays as if they are coming from the behind of the mirror. At point A' image of the point is formed and we call this image ***virtual image*** which means not real. The distance of the image to the mirror is equal to the distance of the object to the mirror. If we want to draw the image of an object in plane mirrors we follow the given steps below. First look at picture and then follow the steps one by one.

In plane mirrors, the laws of reflection are obeyed while drawing the image of the objects. As it is seen from the picture we send rays from the top and bottom of the object to the mirror and reflect them with the same angle it hits the mirror. The extensions of the reflected rays give us the image of the object. The orientation and height of the image is same as the object. In plane mirrors always *virtual image* is formed.

5.6.2 Images formed by Lenses

Lenses are commonly used to form images by refraction in optical instruments, such as cameras, telescopes, and microscopes. A lens is an optical system with two refracting surfaces. The two types of lenses are convex and concave lenses. A **lens** is a part of a transparent thick glass which is bounded by two spherical surfaces. It is an optical device through which the rays of light converge or diverge before transmitting.

Convex lenses- converging lenses thickest at their center and converge a beam of parallel light to real focus (Figure 5.5a).

Concave lenses-diverging lenses thinnest at their center and diverge a beam of parallel light from a virtual focus (Figure 5.5b).

The distance from the focal point to the lens is called the focal length f.

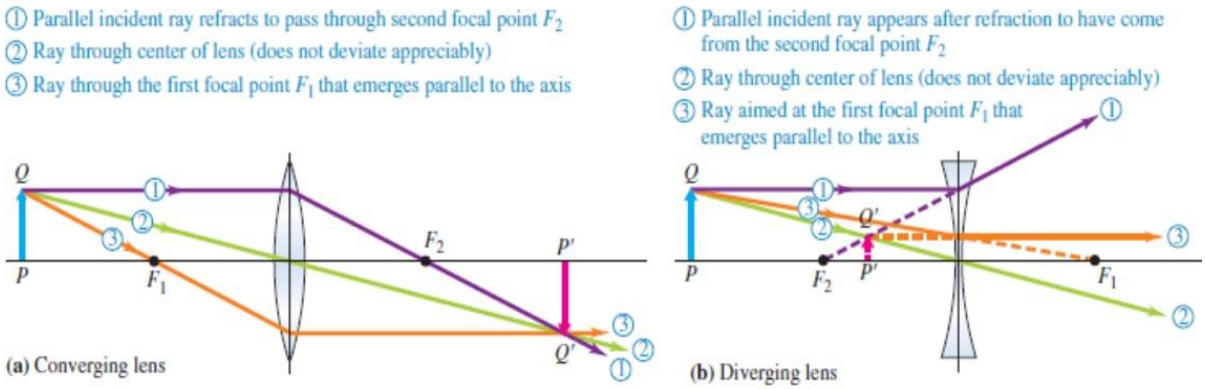


Figure 5.5: image formed by convex (a) and concave lens (b).

The equation that relates object and image distances for a lens is identical to the mirror equation.

$$\frac{1}{s_0}+\frac{1}{s_i}=\frac{1}{f} \quad \ldots\ldots\ldots\

Beyond $2F_1$	Between $2F_2$ and F_2	Real and Inverted	Diminished
Between $2F_1$ and F_1	Beyond $2F_2$	Real and Inverted	Enlarged
At F_1	At infinity	Real and Inverted	Enlarged
At 2 F_1	At $2F_2$	Real and Inverted	Same size
Between F_1 and 0	On the same side as object	Virtual and Erect	Enlarged

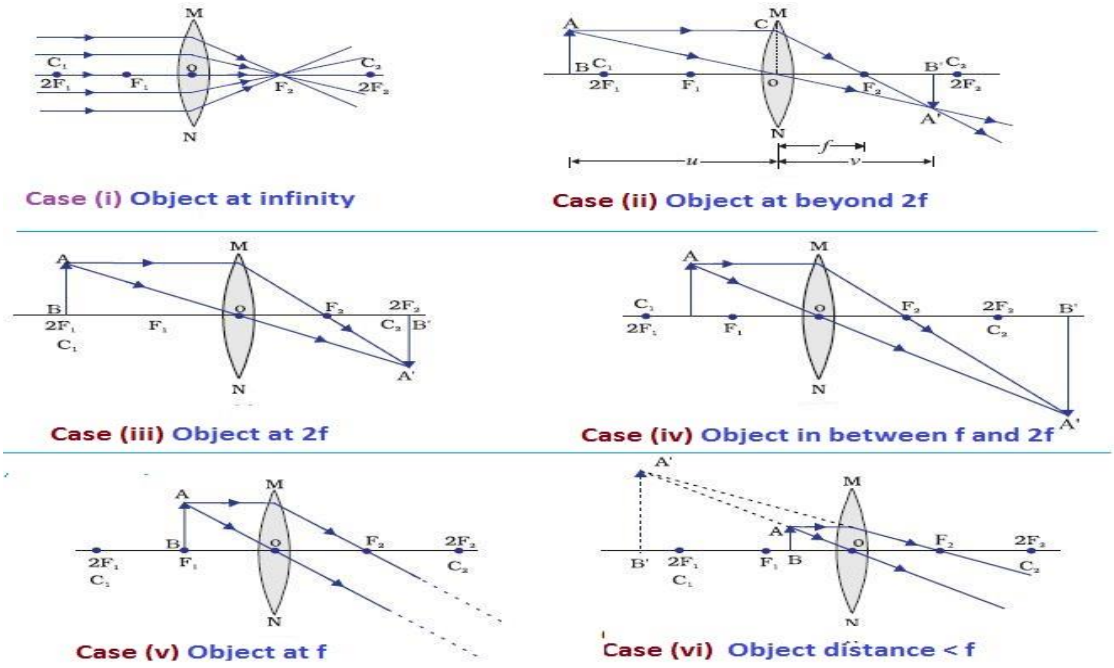

Case (i) Object at infinity
Case (ii) Object at beyond 2f
Case (iii) Object at 2f
Case (iv) Object in between f and 2f
Case (v) Object at f
Case (vi) Object distance < f

Figure 5.6: Image Formation by Concave Lens

Concave lenses include lenses like plano-concave (i.e. these lenses are flat on one side and curved inward on the other), and concave meniscus (i.e. these lenses are curved inward on one side and on the outer side it's curved less strongly).

In case of the concave lens, the images formed are always erect, diminished and virtual images.

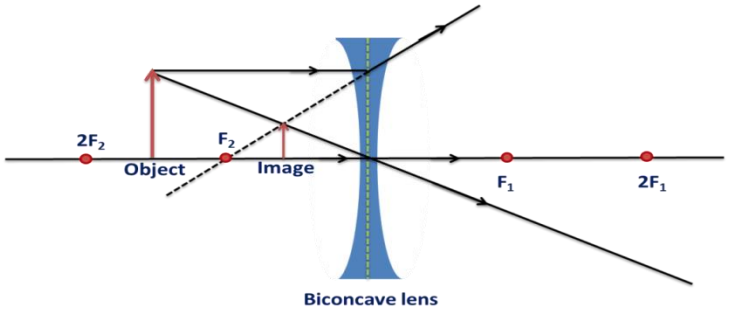


Figure 5.7: image formation by concave lens

Table 5.2: Summary of image formation by concave lens

Object location	**Image location**	**Image nature**	**Image size**
Infinity	At F_2	Virtual and Erect	Highly Diminished
Beyond infinity and 0	Between F_1 and Optical center	Virtual and Erect	Diminished

Here if the object is very far away, the images formed by lenses will be all the more diminished.

Chapter Summery

Periodic motion is a motion of a body which repeats its path of motion back and forth about the equilibrium or mean position. There are two types of oscillatory motion: *linear oscillation* and *circular oscillation.* Oscillators are the basic building blocks of waves. Oscillatory systems are of two types, *mechanical* and *non- mechanical systems*.

Period (T): is the time required to complete one full cycle of vibration or oscillation.

Frequency (*f*): The frequency is the number of complete oscillations or cycles per unit time.

$$f = \frac{1}{T}$$

Amplitude (A): is the maximum displacement of the oscillator from the equilibrium

Simple harmonic motion is a special type of oscillatory motion caused by a restoring force which obeys Hooke's law.

Displacement: $x = A\sin(\omega t)$; (if the oscillator starts from the equilibrium position)

Velocity: $V = \omega A\cos(\omega t)$

Acceleration: $a = -\omega^2 A\sin(\omega t) = -\omega^2 x$

The *potential energy* of SHM is given by: $PE = \frac{1}{2}kx^2$

The *kinetic energy* of SHM is given by: $KE = \frac{1}{2}mv^2$

Therefore the *total energy* of the oscillator performing SHM is: $E = \frac{1}{2}kA^2$.

Wave is a disturbance from normal or equilibrium condition that travels, or propagates, carrying energy and momentum through space without the transport of matter. Waves can be categorized as Mechanical and Electromagnetic waves based on the need of material medium for its propagation. Waves can also be categorized as transverse and longitudinal waves based on the way they are propagating.

Resonance is the increase in amplitude of oscillation of an electric or mechanical system exposed to a periodic force whose frequency is equal or very close to the natural undamped frequency of the system.

In plane mirrors always *virtual image* is formed.

A **lens** is a part of a transparent thick glass which is bounded by two spherical surfaces. It is an optical device through which the rays of light converge or diverge before transmitting.

Convex lenses- converging lenses thickest at their center and converge a beam of parallel light to real focus.

Concave lenses-diverging lenses thinnest at their center and diverge a beam of parallel light from a virtual focus.

Chapter Review questions and Problems

1. How would the period of a simple pendulum be affected if it were located on the moon instead of the earth?
2. What effect would the temperature have on the time kept by a pendulum clock if the pendulum rod increases in length with an increase in temperature?
3. What kind of graph would result if the period T were graphed as a function of the square root of the length, *l*.
4. What effect does the mass of the ball have on the period of a simple pendulum? What would be the effect of replacing the steel ball with a wooden ball, a lead ball, and a ping pong ball of the same size?

CHAPTER SIX

ELECTROMAGNETISM AND ELECTRONICS

This chapter of Electromagnetism and Electronics is intended for students enrolling as Natural Science Students in the Ethiopian Universities. The chapter consists of Ten Sub- units: Concept of Coulomb's Law and Electric Field , electric charge; electric potential; Current , resistance and Ohm's law capacitance; Electric power, Equivalent resistance and Kirchhoff's law, Magnetic field and Magnetic flux, Electromagnetic Induction, Insulators, Conductors and semiconductors, Diodes/Characteristic curves and Transistors.

The study of electric charge involves differentiating between conductors and insulators and using them to demonstrate the existence of charges. In addition, Coulomb's law will be stated and its expression derived and used in calculations. Along with this, electric field, dipole moments; potential energy; and torque on an electric dipole. And flux of electric field will be defined. Their expressions will be derived and also used to solve problems.

Under electric potentials, the sub-topics will be handled and relevant expressions shall be derived and used for calculations. In the third section of the module, capacitance, properties of capacitors, including capacitors with dielectric will be learnt. For the section on Direct current and circuits, derivation of microscopic form of Ohm's law will be among the expressions to be derived. Also analysis of equivalent circuits will be dealt with. Finally Magnetism will form the last part of the module of which Ampere's circuital law will form part of it.

Learning Objectives: At the end of this section, you will be able to:

- Describe the electric force, both qualitatively and quantitatively
- Define electric potential, voltage, and potential difference
- Apply conservation of energy to electric systems
- Define the unit of electrical current
- State Analyze complex circuits using Kirchhoff's rules
- Explain attraction and repulsion by magnets
- Describe the historical and contemporary applications of magnet
- Define magnetic flux

- Use Faraday's law to determine the magnitude of induced emf in a closed loop due to changing magnetic flux through the loop

6.1. Coulomb's Law and Electric Fields

Electric Charge

Electric charge is an inherent property of matter that makes it to have and experience electrical and magnetic characteristics. The effect of electric charge is observed when electronic devices are activated with the click of a switch like computers, cell phones, television. And also it is seen in natural phenomena during a heavy thunderstorm as a flash of lightning.

Kinds Of Electric Charges

Many experiments in the past including the traditional comb and hair, have revealed that there are generally two basic types of electric charges in nature. These two types of charges are positive and negative charges.The psitive charge is the quantity of charge carried by a proton and the negative charge is the charge carried by an electron. Charge is a physical property of an object and is a measurable quantity. The SI unit of charge is coulomb (C), and its symbol is either Q or q. The smallest amount of charge to be carried by a material is the charge of an electron and its amount is

$$1e = 1.6 \text{ x } 10^{-19} \text{ C}$$

The interaction of electric charges is governed by the following basic law of electrostatics which states that:

- Like charges repel each other.
- Unlike charges attract each other

The qualitative aspect of Coulomb's law is also governed by these two laws.

Experiments with electric charges have shown that two objects having electric charges exert an electric force on each other (see Figure 6.1). The magnitude of the force is linearly proportional to the net charge on each object and inversely proportional to the square of the distance between them. (Interestingly, the electric force does not depend on the mass of the charged body.) The

direction of the force vector is along the imaginary line joining the two objects and is dictated by the signs of the charges involved.

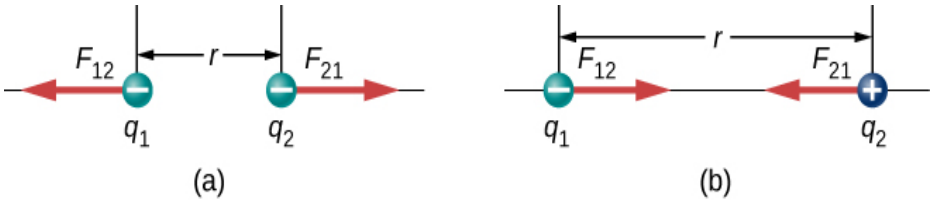


Figure 6.1: The electrostatic force $\vec{F}$ between point charges q_1 and $q_2$separated by a distance r is given by Coulomb's law. Note that Newton's third law (every force exerted creates an equal and opposite force) applies as usual—the force on q_1 is equal in magnitude and opposite in direction to the force it exerts on q_2 . (a)Like charges; (b) unlike charges

Let q_1 and q_2 be the net charges of two bodies separated by the vector displacement $\vec{r}_{12}$. The magnitude of the electric force $\vec{F}_{12}$ on one of the charged body by the other is proportional accordingly the relation given by equation (6.1).

$$F_{12} \alpha \frac{q_1 q_2}{r^2_{12}} \qquad (6.1)$$

This proportionality becomes equality with the introduction of proportionality constant. Therefore, the magnitude of the electric force between two electrically charged particles is

$$\vec{F}_{12}(r) = \frac{K|q_1 q_{21}|}{r_{12}^{\ 2}} \hat{r} \ (6.2)$$

Where the proportionality constant $K = \frac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9 \frac{N.m^2}{C^2}$

$$\varepsilon_0 = 8.85X10^{-12} \frac{C^2}{N.m^2}$$

ε_0 is the permittivity of free space. And equation 6.2 is known as Coulomb's law.

Electric Forces due to system of point charges

Considering a system of N point charges, the net electric force on the test charge is simply the vector sum of each individual electric force exerted on it by each of the individual test charges. Thus, we can calculate the net force on the test charge q_0 by calculating the force on it from each source charge, taken one at a time, and then adding all those forces together(as vectors). This

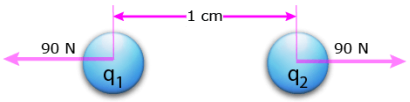
ability to simply add up individual forces in this way is referred to as the **principle of superposition**, and is one of the more important features of the electric force. In mathematical form, this becomes:

$$\vec{F} = k\sum_{i=1}^{N} \frac{q_i q_0}{r_{i0}^2}\hat{r}_{i0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 6.3$$

Example

The force between two identical charges separated by 1 cm is equal to 90 N. What is the magnitude of the two charges?

Solution: First, draw a force diagram of the problem.



Given:

F = 90 N

q1 = charge of first body

q2 = charge of second body

r = 1 cm

Use the Coulomb's Law equation

$$F = \frac{kq_1q_2}{r^2}$$

The problem says the two charges are identical, so

$q_1 = q_2 = q$

Substitute this into the equation

$$q^2 = \frac{Fr^2}{k}$$

Since we want the charges, solve for q

Enter the values for the variables. Remember to convert 1 cm to 0.01 meters to keep the units consistent.

$$q = \sqrt{\frac{(90N)(0.01m)^2}{8.89\times10^9\, N.m/C^2}}$$

q = $\pm 1.00\times10^{-6}$ C or q= $\pm 1\mu C$

Since the charges are identical, they are either positive or negative. This force is repulsive.

Activity:

Two neutrally charged bodies are separated by 1cm. Electrons are removed from one body and placed on the second body until a force of 1×10^{-6} N is generated between them. How many electrons were transferred between the bodies?

Electric Field

Self Diagnostic Test

1. When measuring an electric field, could we use a negative rather than a positive test charge?
2. During fair weather, the electric field due to the net charge on Earth points downward. Is Earth charged positively or negatively?
3. If the electric field at a point on the line between two charges is zero, what do you know about the charges?
4. Two charges lie along the x-axis. Is it true that the net electric field always vanishes at some point (other than infinity) along the x-axis?

Qualitatively, electric field can be defined as the region around a point charged particle where all other charged particles experience electrical force. For point charge q located at position r, the electrostatic forces on a test charge q_0 is given by

$$\vec{F}(r) = \frac{K|q\ q_0|}{r^2}\hat{r} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 6.4$$

Where q_0 is a small positive charge and used to test the presence of the electric field around the charged body.

Electric field is the property of a source charge and does not depend on the test charge. And mathematically the electric field for a point charge q is obtained from

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{kq}{r^2}\hat{r} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6.5$$

The direction of any electric field vector is the same as the direction of the electric force vector that the field would apply to a positive test charge placed in that field. Such a charge would be repelled by positive source charges (the force on it would point away from the positive source charge) but attracted to negative charges (the force points toward the negative source).By convention, all electric fields point away from positive source charges and point toward negative source charges.

Electric Fields due to Charge Distributions

Considering a system having N number of charges denoted as q_1, q_2, q_3, ….., q_N with position vectors r_1,r_2, r_3,…., r_N respectively. The electric field at a point P due to these discrete charges can be calculated according to the Coulomb's law shown in the section above. The total electric field at the test point P can be calculated using the superposition principle.

$$\vec{E} = k\sum_{i=1}^{N} \frac{q_i}{r_i^2}\hat{r}_i \qquad \text{……} \qquad 6.5$$

Example

The electric field of an atom in an ionized helium atom, the most probable distance between the nucleus and the electron is r = 26.5 x 10^{-12}m. What is the electric field due to the nucleus at the location of the electron?

Solution: The electric field is calculated by

$$\vec{E} = k\frac{q}{r^2}\hat{r}$$

Here q=2e= 2(1.6x 10^{-19}C) (since there are two protons) and r is given; substituting gives

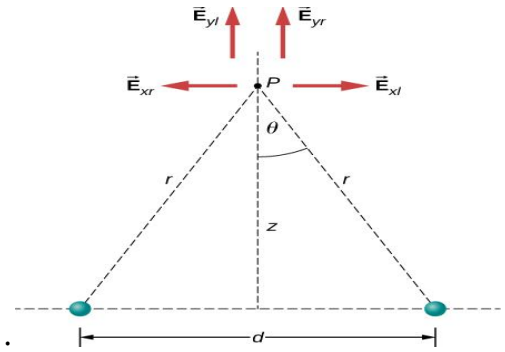
$$E = (9.0x10^{9})\frac{2\left(1.6\times10^{-16}\right)}{(26.5\times10^{-12})^2} = 4.1 \text{ x } 10^{12}\ \text{N/m}$$

Activity

Two equal charges are given:

(a) Find the electric field (magnitude and direction) a distance z above the midpoint between two equal charges +q that are a distance d apart (Figure). Check that your result is consistent with what you'd expect when z >> d

(b) The same as part (a), only this time make the right-hand charge −q instead of +q.



Electric Field Lines

Electric field lines are models for representing electric field distribution over space around charged bodies. For a positive source charge, the electric field points radially outward from the source charge and for a negative one, it points radially inwards as shown in Figure 6.2 below.

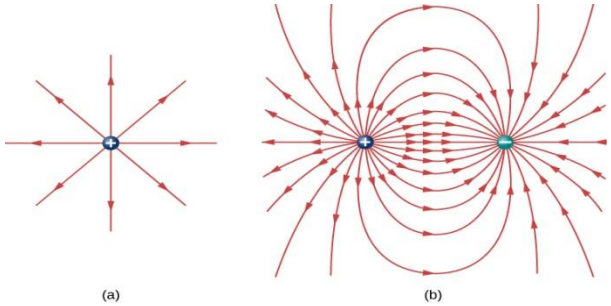


Figure 6.2: (a) The electric field line diagram of a positive point charge. (b) The field line diagram of a dipole. In both diagrams, the magnitude of the field is indicated by the field line density. The field vectors (not shown here) are everywhere tangent to the field lines

6.2. Electric Potential

Self Diagnostic Test

1. What is the quantity that describes the vector space electrical property of a charge?
2. Can you state the relationship between work and potential energy?

The energy released in a lightning strike is an excellent illustration of the vast quantities of energy that may be stored and released by an electric potential difference. In this section, the

amount of energy released in a lightning strike can be calculated and how this varies with the height of the clouds from the ground.

6.2.1 Electric potential energy

When a free positive charge q is accelerated by an electric field, it is given kinetic energy (Figure 6.3). The process is analogous to an object being accelerated by a gravitational field, as if the charge were going down an electrical hill where its electric potential energy is converted into kinetic energy, although of course the sources of the forces are very different. Let us explore the work done on a charge q by the electric field in this process, so that we may develop a definition of electric potential energy.

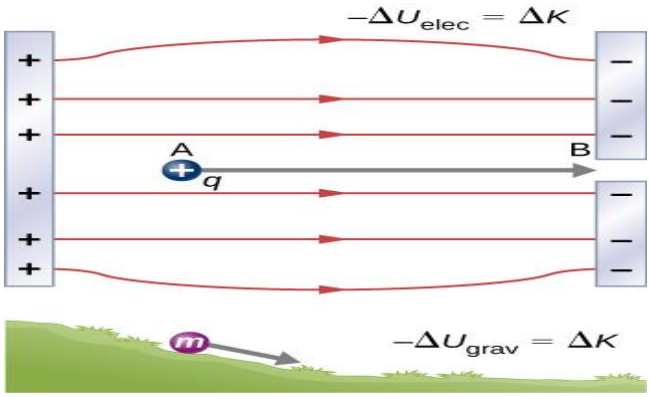
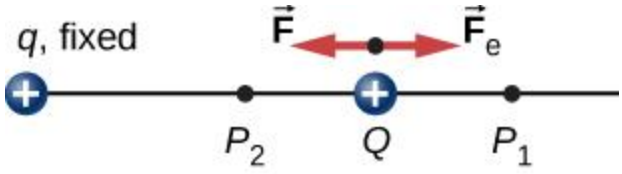


Figure 6.3: The electrostatic or Coulomb force is conservative, which means that the work done on q is independent of the path taken, as we will demonstrate later. This is exactly analogous to the gravitational force. When a force is conservative, it is possible to define a potential energy associated with the force. It is usually easier to work with the potential energy (because it depends only on position) than to calculate the work directly.

A charge accelerated by an electric field is analogous to a mass going down a hill. In both cases, potential energy decreases as kinetic energy increases, $-\Delta U = \Delta K$. Work is done by a force, but since this force is conservative, we can write W= -ΔU.

To show this explicitly, consider an electric charge +q fixed at the origin and move another charge +Q toward q in such a manner that, at each instant, the applied force $\vec{F}$ exactly balances the electric force $\vec{F}_e$ on Q (Figure). The work done by the applied force $\vec{F}$ on the charge Q changes the potential energy of Q. We call this potential energy the electrical potential energy of Q. Displacement of "test" charge Q in the presence of fixed "source" charge q.



The work done W_{12} by the applied force $\vec{F}$ when the charged particle moves from P_1 to P_2 may be calculated by

$$W_{12} = \vec{F}_e \bullet \vec{r} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 6.6$$

Where, $\vec{r}$ is the displacement of the charged particle from point 1 to point 2.

Then,

$$W_{12} = F_e r \cos\theta \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad 6.7$$

Where, F_e and r are the magnitudes of the electric force $\vec{F}_e$ and *the* displacement $\vec{r}$ respectively.

Since the electric force and the displacement are parallel, the angle θ between them is zero, and hence the above equation becomes

$$W_{12} = F_e r \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ .8$$

Also the electric force between q and Q separated by a distance r from Coulomb's law is given by

$$F_e = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 6.9$$

Then substituting eq.6.9 into the work equation,

$$W_{12} = \left(\frac{1}{4\pi\varepsilon_0}\frac{qQ}{r^2}\right)(r)$$

$$W_{12} = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 6.10$$

This work done on the charge Q is exactly equivalent to the potential energy of the configuration of the two (q and Q) systems of charges.

Therefore, we define the electrical potential energy of any two systems of charges q_1 and q_2 is separated by a distance r_{12} is given by:

$$U_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}} \qquad \ldots\ldots\ldots\ldots\ldots \quad 6.11$$

Where, we assumed that the initial position of the two charges before the configuration shown in the figure above is infinity. So the quantity U_{12} is the amount of work done on the two charges to bring them from infinity to the separation r_{12}.

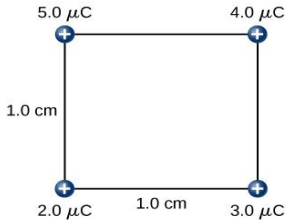
For systems of charges more than two, $q_1, q_2, \ldots, q_n$, the electric potential energy is given by

$$U = \sum_{i,j}^{n} \frac{1}{4\pi\varepsilon_0}\left(\frac{q_i q_j}{r_{ij}}\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad 6.12$$

Note that the sign of the charges will not be ignored if the charges are negative.

Example

Find the electric potential energy in assembling four charges at the vertices of a square of side 1.0 cm, starting each charge from infinity as shown in the figure.



Solution:

From the formula of electric potential energy of systems of charges above,

$$U = \sum_{i,j}^{n} \frac{1}{4\pi\varepsilon_0}\left(\frac{q_i q_j}{r_{ij}}\right)$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_1 q_4}{r_{14}} + \frac{q_2 q_3}{r_{23}} + \frac{q_2 q_4}{r_{24}} + \frac{q_3 q_4}{r_{34}}\right)\right]$$

$$= \frac{1}{4\pi \times 8.85\times10^{-12}}\left[\left(\frac{5x2}{1\times10^{-2}} + \frac{5\times4}{1\times10^{-2}} + \frac{5\times3}{\sqrt{(1\times10^{-2})(1\times10^{-2})}} + \frac{4\times3}{1\times10^{-2}} + \frac{4\times2}{\sqrt{(1\times10^{-2})(1\times10^{-2})}} + \frac{3\times2}{1\times10}\right)\times10^{-9}\right]$$

$U = 57.8\text{J}$

The superposition principle holds for electric potential energy; the potential energy of a system of multiple charges is the sum of the potential energies of the individual pairs.

Definition: Electric Potential

The electric potential energy per unit charge is

$$V = \frac{U}{q} \quad \text{……..} \quad 6.13$$

Since U is proportional to q, the dependence on q cancels. Thus, V does not depend on q. The change in potential energy U is crucial, so we are concerned with the difference in potential or potential difference V between two points, where

$$V = V_B - V_A = \frac{U}{q} \quad \text{……..} \quad 6.14$$

Electric Potential Difference

The electric potential difference between points A and B, $V_A - V_B$, is defined to be the change in potential energy of a charge q moved from A to B, divided by the charge. Units of potential difference are joules per coulomb, given the name volt (V) after Alessandro Volta.

The familiar term voltage is the common name for electric potential difference. Keep in mind that whenever a voltage is quoted, it is understood to be the potential difference between two points. For example, every battery has two terminals, and its voltage is the potential difference between them. More fundamentally, the point you choose to be zero volts is arbitrary. This is analogous to the fact that gravitational potential energy has an arbitrary zero, such as sea level or perhaps a lecture hall floor. It is worthwhile to emphasize the distinction between potential difference and electrical potential energy.

Potential Difference and Electrical Potential Energy

The relationship between potential difference (or voltage) and electrical potential energy is given by

$$V = \frac{U}{q}$$

Voltage is not the same as energy. Voltage is the energy per unit charge. Thus, a motorcycle battery and a car battery can both have the same voltage (more precisely, the same potential difference between battery terminals), yet one stores much more energy than the other because $U = qV$. The car battery can move more charge than the motorcycle battery, although both are 12-V batteries

Example

You have a 12.0-V motorcycle battery that can move 5000 C of charge, and a 12.0-V car battery that can move 60,000 C of charge. How much energy does each deliver?

Solution:

$$V = \frac{U}{q}$$

$$U = qV$$

$U_1 = q_1 V$ = (12V x 5000C) = 60000J

$U_2 = q_2 V$ = (12V x 60,000C) =720,000J = 0.7MJ

Activity:

How Many Electrons Move through a Headlight Each Second? When a 12.0-V car battery powers a single 30.0-W headlight, how many electrons pass through it each second?

6.3. Current, Resistance and Ohm's Law

In this section, we study the electrical current through a material, where the electrical current is the rate of flow of charge. We also examine a characteristic of materials known as the resistance. Resistance is a measure of how much a material impedes the flow of charge, and it will be shown that the resistance depends on temperature. In general, a good conductor, such as copper, gold, or silver, has very low resistance.

Self Diagnostic Test

1. Can you state the difference between electrostatics and Electricity Current?
2. What is the basic requirement for the motion of electric charges inside an electric field?
3. What is the main driving agent for electric charges to flow through a conductor?
4. Can you imagine how charges flow through a conductor?

Up to now, we have considered primarily static charges. When charges did move, they were accelerated in response to an electrical field created by a voltage difference. The charges lost potential energy and gained kinetic energy as they traveled through a potential difference where the electrical field did work on the charge.

Although charges do not require a material to flow through, the majority of this section deals with understanding the movement of charges through a material. The rate at which the charges flow past a location; that is the amount of charge per unit time is known as the electrical current. It is measured in units called amperes. When charges flow through a medium, the current depends on the voltage applied the material through which the charges flow, and the state of the material. Of particular interest is the motion of charges in a conducting wire. In previous sections, charges were accelerated due to the force provided by an electrical field, losing potential energy and gaining kinetic energy. In this section, we will discuss the situation of the force provided by an electrical field in a conductor, where charges lose kinetic energy to the material reaching a constant velocity, known as the "drift velocity." This is analogous to an object falling through the atmosphere and losing kinetic energy to the air, reaching a constant terminal velocity.

Activity:

You may have noticed that circuit breakers in your home and fuses in your car are rated in amps (or amperes). But what is the ampere and what does it measure?

The average current *I* through a given cross-sectional area *A* is the rate at which charge flows,

$$I = \frac{\Delta Q}{\Delta t} \qquad 6.15$$

Where ΔQ is the amount of charge passing through a given area in time Δt (Figure 6.4). The SI unit for current is the ampere (A), named for the French physicist André-Marie Ampère (1775–

1836). Since I=ΔQ/Δt, we see that an ampere is defined as one coulomb of charge passing through a given area per second:

$1A = \frac{1C}{1s}$ = 6.25 x 10^{18}electrons flowing through the area *A* each second.

Most electrical appliances are rated in amperes (or amps) required for proper operation, as are fuses and circuit breakers.

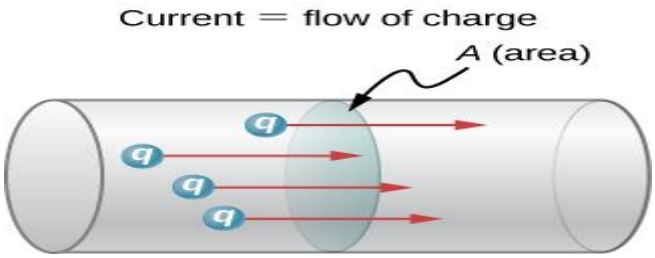


Figure 6.4: Current flow in a conductor

What is the average current involved when a truck battery sets in motion 720 C of charge in 4.00 s while starting an engine? (b) How long does it take 1.00 C of charge to flow from the battery?

Solution

a. Entering the given values for charge and time into the definition of current gives

$$I = \frac{Q}{t}$$

$$= \frac{720C}{4s} = 180C/s = 180A$$

We can think of various devices; such as batteries, generators, wall outlets, and so on—that are necessary to maintain a current. All such devices create a potential difference and are referred to as voltage sources. When a voltage source is connected to a conductor, it applies a potential difference V that creates an electrical field. The electrical field, in turn, exerts force on free charges, causing current. The amount of current depends not only on the magnitude of the voltage, but also on the characteristics of the material that the current is flowing through. The material can resist the flow of the charges, and the measure of how much a material resists the flow of charges is known as the resistivity. This resistivity is crudely analogous to the friction between two materials that resists motion.

Resistivity

When a voltage is applied to a conductor, an electrical field **E** is created, and charges in the conductor feel a force due to the electrical field. The current density J that results depends on the electrical field and the properties of the material. This dependence can be very complex. In some materials, including metals at a given temperature, the current density is approximately proportional to the electrical field. In these cases, the current density can be modeled as

$$\vec{J} = \sigma\vec{E} \qquad 6.16$$

Where, σ is electrical conductivity and it is analogous to thermal conductivity and is a measure of a material's ability to conduct or transmit electricity. Conductors have a higher electrical conductivity than insulators. Since the electrical conductivity σ is, the units are

$$\sigma = \frac{[J]}{E} = \frac{A/m^2}{V/m} == \frac{A}{Vm}$$

Here, we define a unit named the ohm with the Greek symbol uppercase omega, Ω. One ohm equals one volt per ampere.

Conductivity is an intrinsic property of a material. Another intrinsic property of a material is the resistivity, or electrical resistivity. The resistivity of a material is a measure of how strongly a material opposes the flow of electrical current. The symbol for resistivity is the lowercase Greek letter ρ \rho, and resistivity is the reciprocal of electrical conductivity:

The unit of resistivity in SI units is the ohm-meter (Ω - m). We can define the resistivity in terms of the electrical field and the current density,

$$\rho = \frac{\vec{E}}{J}. \qquad 6.17$$

Ohm's Law states that " the voltage applied across the end points of a conductor is proportional to the flow of electric current".

Mathematically

$$V\ \alpha\ I\ \Longrightarrow \frac{V}{I} = Contant = Resistance\ (R) \qquad 6.18$$

The greater the resistivity, the larger the field needed to produce a given current density. The lower the resistivity, the larger the current density produced by a given electrical field. Good conductors have a high conductivity and low resistivity. Good insulators have a low conductivity and a high resistivity.

6.4. Electrical Energy and Power

In an electric circuit, electrical energy is continuously converted into other forms of energy. The electrical field, supplied by the voltage source, accelerates the free electrons, increasing their kinetic energy for a short time. In Work and Kinetic Energy, we defined power as the rate at which work is done by a force measured in watts. Power can also be defined as the rate at which energy is transferred.

In an Electric Potential, electrical field exists between two potentials, which points from the higher potential to the lower potential. Recall that the electrical potential is defined as the potential energy per charge, V=Uq, and the ΔQ loses potential energy moving through the potential difference. If the conductor has a length l, the electric field E is given by,

$$E = \frac{V_2 - V_1}{l} = \frac{V}{l} \qquad 6.19$$

Then the work W is

$$W = Fl = (QE)l = Q(V/l)\, l = QV = U \qquad 6.20$$

Hence, the power is

$$P = \frac{U}{t} = \frac{QV}{t} = \frac{Q}{t}V = IV = I^2R = \frac{V^2}{R} \quad \text{, using Ohm's law.} \qquad 6.21$$

6.5. Equivalent Resistance and Kirchhoff's Rule

If several resistors are connected together and connected to a battery, the current supplied by the battery depends on the equivalent resistance of the circuit. The equivalent resistance of a combination of resistors depends on both their individual values and how they are connected. The simplest combinations of resistors are series and parallel connections (as shown in Figure 6.5). In a series circuit, the output current of the first resistor flows into the input of the second

resistor; therefore, the current is the same in each resistor. In a parallel circuit, all of the resistor leads on one side of the resistors are connected together and all the leads on the other side are connected together. In the case of a parallel configuration, each resistor has the same potential drop across it, and the currents through each resistor may be different, depending on the resistor. The sum of the individual currents equals the current that flows into the parallel connections.

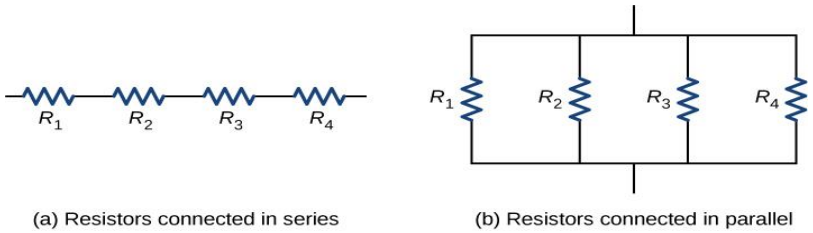


Figure 6.5: Four resistors connected in series (a) and parallel (b)

Resistors in Series

If *N* resistors are connected in series, the equivalent resistance is

$$R_{eq} = R_1 + R_2 + R_3 + \ldots R_N = \sum_{i=1}^{N} R_i \qquad \ldots\ldots\ldots \quad 6.22$$

Resistors in Parallel

For any number of *N* resistors, the equivalent resistance *R*eq of a parallel connection is related to the individual resistances by

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots \frac{1}{R_N} = \sum_{i=1}^{N} \left(\frac{1}{R_i}\right) \qquad 6.23$$

Kirchhoff's Circuit Rule

Kirchhoff's Circuit Laws allow us to solve complex circuit problems by defining a set of basic network laws and theorems for the voltages and currents around a circuit.

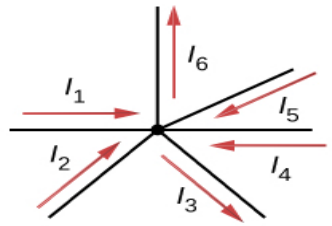
1. Kirchhoff's First Rule (Junction Rule)

states that the "*total current or charge entering a junction or node is exactly equal to the charge leaving the node as it has no other place to go except to leave, as no charge is lost within the node*".

In other words the algebraic sum of ALL the currents entering and leaving a node must be equal to zero, $I_{(exiting)} + I_{(entering)} = 0$. This idea by Kirchhoff is commonly known as the **Conservation of Charge**.

$$\Sigma I\text{in} = \Sigma\, I\text{out}. \qquad 6.24$$

Kirchhoff's first rule applies to the charge entering and leaving a junction (Figure 6.6). As stated earlier, a junction, or node, is a connection of three or more wires. Current is the flow of charge, and charge is conserved; thus, whatever charge flows into the junction must flow out.



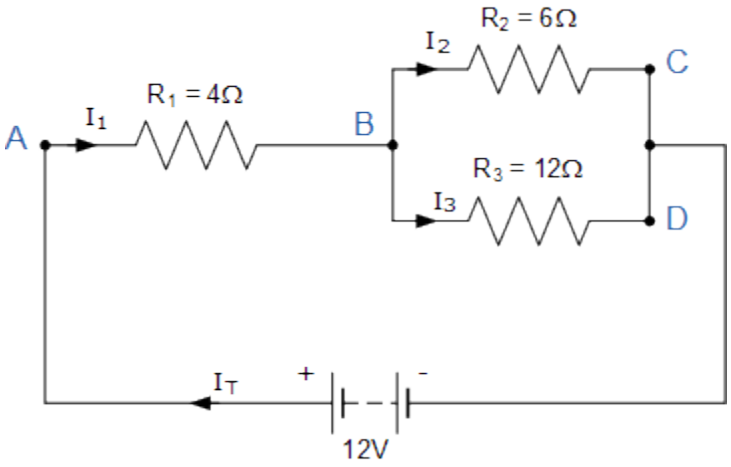
$$\sum I_{in} = \sum I_{out}$$
$$I_1 + I_2 + I_4 + I_5 = I_3 + I_6$$

Figure 6.6: Currents entering a junction and exiting a junction

Charge must be conserved, so the sum of currents into a junction must be equal to the sum of currents out of the junction.

Example

Find the currents flowing around the following circuit using Kirchhoff's Current Law only



I_T is the total current flowing around the circuit driven by the 12V supply voltage. At point A, I_1 is equal to I_T, thus there will be an I_1*R voltage drop across resistor R_1.

The circuit has 2 branches, 3 nodes (B, C and D) and 2 independent loops, thus the I*R voltage drops around the two loops will be:

- Loop ABC $\Rightarrow$ $12 = 4I_1 + 6I_2$
- Loop ABD $\Rightarrow$ $12 = 4I_1 + 12I_3$

Since Kirchhoff's current law states that at node B, $I_1 = I_2 + I_3$, we can therefore substitute current I_1 for $(I_2 + I_3)$ in both of the following loop equations and then simplify.

Kirchhoff's Loop Equations

Loop (ABC)

$$12 = 4I_1 - 6I_2$$
$$12 = 4(I_{2-}I_3) - 6I_3$$
$$12 = 4I_2 - 4I_3 - 6I_2$$
$$12 = 10I_2 - 4I_3$$

Loop (ABD)

$$12 = 4I_1 - 12I_3$$
$$12 = 4(I_2 - I_3) - 12I_3$$
$$12 = 4I_2 - 4I_3 - 12I_3$$
$$12 = 4I_2 - 16I_3$$

We now have two simultaneous equations that relate to the currents flowing around the circuit.

Equation No 1 : $12 = 10I_2 + 4I_3$

Equation No 2 : $12 = 4I_2 + 16I_3$

By multiplying the first equation (Loop ABC) by 4 and subtracting Loop ABD from Loop ABC, we can be reduced both equations to give us the values of I_2 and I_3

Equation No 1 : $12 = 10I_2 + 4I_3$ (x4) $\Rightarrow$ $48 = 40I_2 + 16I_3$

Equation No 2 : $12 = 4I_2 + 16I_3$ (x1) $\Rightarrow$ $12 = 4I_2 + 16I_3$

Equation No 1 - Eq. No 2 $\Rightarrow$ $36 = 36I_2 + 0$

Substitution of I_2 in terms of I_3 gives us the value of I_2 as 1.0 Amps

Now we can do the same procedure to find the value of I_3 by multiplying the first equation (Loop ABC) by 4 and the second equation (Loop ABD) by 10. Again by subtracting Loop ABC from Loop ABD, we can be reduced both equations to give us the values of I_2 and I_3

Equation No 1 : $12 = 10I_2 + 4I_3$ (x4) $\Rightarrow$ $48 = 40I_2 + 16I_3$

Equation No 2 : $12 = 4I_2 + 16I_3$ (x10) $\Rightarrow$ $120 = 40I_2 + 160I_3$

Equation No 2 - Eq. No 1 $\Rightarrow$ $72 = 0 + 144I_3$

Thus substitution of I_3 in terms of I_2 gives us the value of I_3 as 0.5 Amps

As Kirchhoff's junction rule states that: $I_1 = I_2 + I_3$

The supply current flowing through resistor R_1 is given as: $1.0 + 0.5 = 1.5$ Amps

Thus $I_1 = I_T = 1.5$ Amps, $I_2 = 1.0$ Amps and $I_3 = 0.5$ Amps and from that information we could calculate the IR voltage drops across the devices and at the various points (nodes) around the circuit.

We could have solved the circuit of example two simply and easily just using Ohm's Law, but we have used *Kirchhoff's Current Law* here to show how it is possible to solve more complex circuits when we can't just simply apply Ohm's Law.

2. Kirchhoff's second rule (loop rule):

States that "*in any closed loop network, the total voltage around the loop is equal to the sum of all the voltage drops within the same loop*" which is also equal to zero. In other words the algebraic sum of all voltages within the loop must be equal to zero. This idea by Kirchhoff is known as the **Conservation of Energy**.

The algebraic sum of changes in potential around any closed circuit path (loop) must be zero:

$$\Sigma V = 0. \qquad 6.25$$

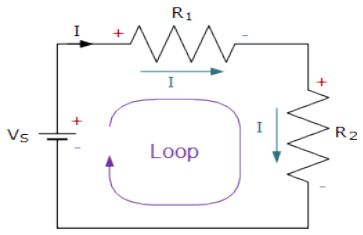


Figure 6.7: Kirchhoff's loop consisting of two resistors and a voltage source

Since the two resistors, R_1 and R_2 (see Figure 6.7) are wired together in a series connection; they are both part of the same loop so the same current must flow through each resistor. Thus the voltage drop across resistor, $V_1 = IR_1$ and the voltage drop across resistor, Kirchhoff's voltage law $V_2 = IR_2$ giving by KVL:

$$V_S + (-IR_1) + (-IR_2) = 0$$
$$\therefore V_S = IR_1 + IR_2$$
$$V_S = I(R_1 + R_2)$$
$$V_S = IR_T$$

Where $R_T = R_1 + R_2$

We can see that applying Kirchhoff's Voltage Law to this single closed loop produces the formula for the equivalent or total resistance in the series circuit and we can expand on this to find the values of the voltage drops around the loop.

$$R_T = R_1 + R_2$$
$$I = \frac{V_S}{R_T} = \frac{V_S}{R_1 + R_2} -$$
$$V_{R1} = IR_1 = \left(\frac{V_S}{R_1 + R_2}\right) R_1$$
$$V_{R2} = IR_2 = \left(\frac{V_S}{R_1 + R_2}\right) R_2$$

Example: Three resistors of values: 10 ohms, 20 ohms and 30 ohms, respectively are connected in series across a 12 volt battery supply. Calculate: a) the total resistance, b) the circuit current, c) the current through each resistor, d) the voltage drop across each resistor, e) verify that Kirchhoff's voltage law, KVL holds true.

a) Total Resistance (R_T)

$$R_T = R_1 + R_2 + R_3 = 10\Omega + 20\Omega + 30\Omega = 60\Omega$$

Then the total circuit resistance R_T is equal to 60Ω

b) Circuit Current (I)

$$I = \frac{V_S}{R_T} = \frac{12}{60} = 0.2A$$

Thus the total circuit current I is equal to 0.2 amperes or 200mA

c) Current through Each Resistor

The resistors are wired together in series; they are all part of the same loop and therefore each experience the same amount of current. Thus:

$$I_{R1} = I_{R2} = I_{R3} = I_{SERIES} = 0.2 \text{ amperes}$$

d) Voltage Drop across Each Resistor

$$V_{R1} = I \times R_1 = 0.2 \times 10 = 2 \text{ volts}$$
$$V_{R2} = I \times R_2 = 0.2 \times 20 = 4 \text{ volts}$$
$$V_{R3} = I \times R_3 = 0.2 \times 30 = 6 \text{ volts}$$

e) Verify Kirchhoff's Voltage Law

$$V_S + (-IR_1) + (-IR_2) + (-IR_3) = 0$$
$$12 + (-0.2 \times 10) + (-0.2 \times 20) + (-0.2 \times 30) = 0$$
$$12 + (-2) + (-4) + (-6) = 0$$
$$12 - 2 - 4 - 6 = 0$$

Thus Kirchhoff's voltage law holds true as the individual voltage drops around the closed loop add up to the total.

6.6. Magnetic Field and Magnetic Flux

Self Diagnostic Test

1. Do you think that there is a relationship between electric current and magnetism?
2. What are the sources of magnetism?
3. State the similarities and differences between electric field and magnetic field

In the previous sections, we have been studying electrostatic forces and fields, which are caused by electric charges at rest. These electric fields can move other free charges, such as producing a current in a circuit; however, the electrostatic forces and fields themselves come from other static charges. In this section, we see that when an electric charge moves, it generates other forces and fields. These additional forces and fields are what we commonly call ***magnetism***.

Before we examine the origins of magnetism, we first describe what it is and how magnetic fields behave. Once we are more familiar with magnetic effects, we can explain how they arise from the behavior of atoms and molecules, and how magnetism is related to electricity. The connection between electricity and magnetism is fascinating from a theoretical point of view, but it is also immensely practical, as shown by an industrial electromagnet that can lift thousands of pounds of metal.

Contemporary Applications of Magnetism

Today, magnetism plays many important roles in our lives. Physicists' understanding of magnetism has enabled the development of technologies that affect both individuals and society. The electronic tablet in your purse or backpack, for example, wouldn't have been possible without the applications of magnetism and electricity on a small scale.

We have outlined the properties of magnets, described how they behave, and listed some of the applications of magnetic properties. Even though there are no such things as isolated magnetic charges, we can still define the attraction and repulsion of magnets as based on a field. In this section, we define the magnetic field, determine its direction based on the right-hand rule, and discuss how to draw magnetic field lines.

Definition: Magnetic Field

A magnetic field is defined by the force that a charged particle experiences moving in this field, after we account for the gravitational and any additional electric forces possible on the charge. The magnitude of this force is proportional to the amount of charge q, the speed of the charged particle v, and the magnitude of the applied magnetic field. The direction of this force is perpendicular to both the direction of the moving charged particle and the direction of the applied magnetic field. Based on these observations, we define the magnetic field strength B based on the magnetic force $\vec{F}$ on a charge q moving at velocity as the cross product of the velocity and magnetic field $\vec{B}$, that is,

$$\vec{F} = q\vec{V} \times \vec{B} \qquad 6.26$$

In fact, this is how we define the magnetic field B, in terms of the force on a charged particle moving in a magnetic field. The magnitude of the force is determined from the definition of the cross product as it relates to the magnitudes of each of the vectors. In other words, the magnitude of the force satisfies

$$F = qvB\sin\theta \qquad 6.27$$

Where, θ is the angle between the velocity and the magnetic field.

The SI unit for magnetic field strength B is called the tesla (T) after the eccentric but brilliant inventor Nikola Tesla (1856–1943), where

A smaller unit, called the gauss (G), where 1G = 1 x 10^{-4}T, is sometimes used. The strongest permanent magnets have fields near 2 T; superconducting electromagnets may attain 10 T or more. Earth's magnetic field on its surface is only about or 0.5 G.

The direction of the magnetic force is perpendicular to the plane formed by $\vec{v} and \vec{B}$, as determined by the right-hand rule-1 (or RHR-1), which is illustrated in (Figure 6.8).

Orient your right hand so that your fingers curl in the plane defined by the velocity and magnetic field vectors. Use your right hand and sweep from the velocity toward the magnetic field with your fingers through the smallest angle possible. The magnetic force is directed where your thumb is pointing. If the charge was negative, reverse the direction found by these steps.

Magnetic fields exert forces on moving charges. The direction of the magnetic force on a moving charge is perpendicular to the plane formed by B and follows the right-hand rule-1 (RHR-1) as shown. The magnitude of the force is proportional to q, v, B, and the sine of the angle between v and B.

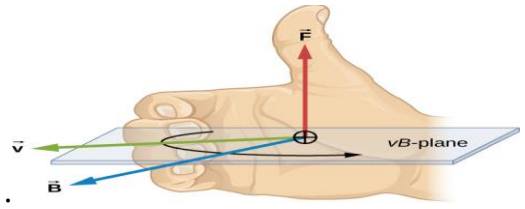


Figure 6.8: The right hand rule

The representation of magnetic fields by magnetic field lines is very useful in visualizing the strength and direction of the magnetic field. As shown in (Figure 6.9), each of these lines forms a closed loop, even if not shown by the constraints of the space available for the figure. The field lines emerge from the north pole (N), loop around to the south pole (S), and continue through the bar magnet back to the north pole.

Magnetic field lines have several hard-and-fast rules:

The direction of the magnetic field is tangent to the field line at any point in space. A small compass will point in the direction of the field line. The strength of the field is proportional to

the closeness of the lines. It is exactly proportional to the number of lines per unit area perpendicular to the lines (called the areal density).

Magnetic field lines can never cross, meaning that the field is unique at any point in space. Magnetic field lines are continuous, forming closed loops without a beginning or end. They are directed from the north pole to the south pole.

The last property is related to the fact that the north and south poles cannot be separated. It is a distinct difference from electric field lines, which generally begin on positive charges and end on negative charges or at infinity. If isolated magnetic charges (referred to as magnetic monopoles) existed, then magnetic field lines would begin and end on them.

Magnetic field lines are defined to have the direction in which a small compass points when placed at a location in the field. The strength of the field is proportional to the closeness (or density) of the lines. If the interior of the magnet could be probed, the field lines would be found to form continuous, closed loops. To fit in a reasonable space, some of these drawings may not show the closing of the loops; however, if enough space were provided, the loops would be closed.

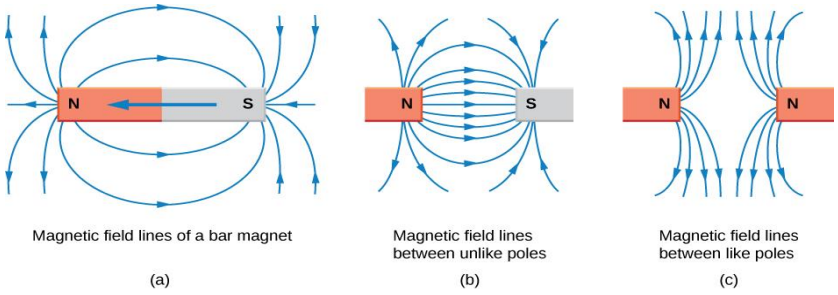


Figure 6.9: Magnetic field lines of a bar magnet(a), Magnetic field lines of unlike poles (b), Magnetic field lines of like poles (c)

Magnetic Flux

To calculate the size of the induced emf we need one more concept; *magnetic flux*. The symbol for magnetic flux is Φ (pronounced “sigh”).

The unit of magnetic flux is the Weber (Wb)

To introduce the idea of magnetic flux consider an area, A in a uniform magnetic field.

When the magnetic force lines are perpendicular to this area (see Figure 6.10) the total magnetic flux (Φ) through the area is defined as the product of B and A.

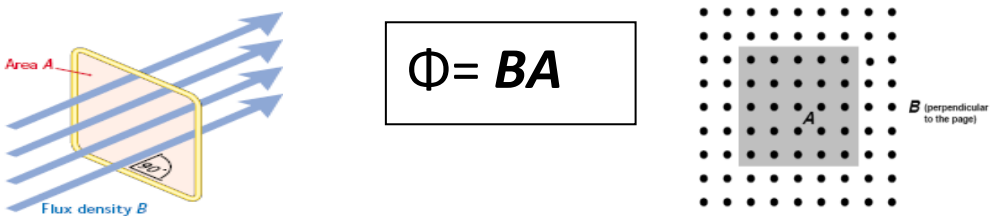


Figure 6.10: Magnetic flux through a loop of area A

The magnetic flux, Φ, can be visualised as the number of magnetic field lines passing through a given area. The number of magnetic field lines per unit area, i.e. B, is then referred to as the density of the magnetic flux or, more properly, the *magnetic flux density*.

6.7. Electromagnetic Induction

SELF DIAGNOSTIC TEST

1. Can an electric current create magnetic field?
2. Can a magnetic field create an electric current?
3. Do you know how a hydroelectric power generator works to produce an electric current?
4. Is there any difference between an electric motor and an electric generator in their physics principle of operation?

The first productive experiments concerning the effects of time-varying magnetic fields were performed by Michael Faraday in 1831. An electromotive force (emf) is induced when the magnetic field in the coil is changed by pushing a bar magnet into or out of the coil. Electromotive force of opposite signs are produced by motion in opposite directions and the directions of emfs are also reversed by reversing poles. The same results are produced if the coil is moved rather than the magnet; it is the relative motion that is important. The faster the motion, the greater the emf, and there is no emf when the magnet is stationary relative to the coil.

Movement of a magnet relative to a coil produces emfs. The same emfs are produced if the coil is moved relative to the magnet. This short-lived emf is only present during the motion. The greater the speed, the greater the magnitude of the emf, and the emf is zero when there is no

motion. Electromagnetic induction occurs when an emf is induced in a coil due to a changing magnetic flux. This is now known as Faraday's Law of Electromagnetic Induction.

The Laws of Electromagnetic Induction

1. Faraday's Law states that the size of the induced emf is proportional to the rate of change of magnetic flux.
2. Lenz's Law states that the direction of the induced emf is always such as to oppose the change producing

Now we are in a position to calculate the induced emf:

$$Inducedemf = -N\frac{\Delta\Phi}{\Delta t} \qquad 6.28$$

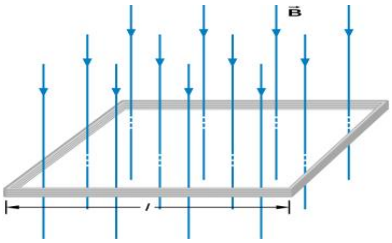
Remember Faraday's Law: The size of the induced emf is proportional to the rate of change of flux.In this case the proportional constant turns out to be N (remember where we came across this before.(the minus sign is a reference to Lenz's Law)

Example

The square coil of (Figure) has sides l=0.2m long and is tightly wound with N=200 turns of wire. The resistance of the coil is R=5.0Ω. The coil is placed in a spatially uniform magnetic field that is directed perpendicular to the face of the coil and whose magnitude is decreasing at a rate $\frac{\Delta B}{\Delta t} = -0.04T/s$. (a) What is the magnitude of the emf induced in the coil? (b) What is the magnitude of the current circulating through the coil?

A square coil with N turns of wire with uniform magnetic field B directed in the downward direction, perpendicular to the coil.

Figure below shows a square coil of the side length l with N turns of wire. A uniform magnetic field B is directed in the downward direction, perpendicular to the coil.



Solution:

a) The flux through the square loop is given by

$$\Phi = \vec{B} \bullet \vec{A} = Bl^2$$

Then the induced emf from Faraday's law is,

$$\varepsilon = N\frac{\Delta\Phi}{\Delta t} = NA\frac{\Delta B}{\Delta t} = (200)(0.2m)^2(0.04T/s)$$

ε = 0.5V

b) Then the current can calculated from Ohm's law

$$\varepsilon = IR$$

$$I = \frac{\varepsilon}{R} = \frac{0.5V}{5\Omega} = 0.1A$$

6.8. Insulators, Conductors and Semiconductors

Electronics is the branch of physics and technology concerned with the design of circuits using transistors and microchips, and with the behavior and movement of electrons in a semiconductor, conductor, vacuum, or gas. Initially, vacuum tubes were used in the process of electrical signal generation, amplification and transmission. With the advent of semiconductor devices like diode, transistor and other solid state electronic components, the vacuum tubes were replaced completely from all fields of applications. All modern gadgets like television, computer, CD player, automatic washing machine, etc., use microprocessors having integrated chips which consists a large number of logic gates, diodes, transistors, resistors, etc.

Objectives

After completing this unit, you should be able to:

- Distinguish between conductors, insulators and semiconductors in terms of the electrical conductivity and the size of the band gap.
- Explain the difference between intrinsic and extrinsic semiconductors.
- Describe the doping process for creating N- and P-type semiconductor materials.
- Describe what junction diode and transistor are and how they are made.
- Draw and label the schematic symbols for a diode and transistors.
- Explain the different bias kinds of a diode and a transistor.

Self Diagnostic Test

1. Explain what criteria are used to classify solids as conductors, semiconductors and insulators? Can you describe the difference among them?

3. Can you mention some advantages of the semiconductors diodes and transistors?

Materials are classified as **conductors, insulators** and **semiconductors** according to their electric conductivity. This classification is purely based on the available number of free electrons within the materials, apart from the bonded orbital electrons. So the word conductivity is used to describe a material's ability to transport electricity. Another means for the classification of materials is the band gap or forbidden energy gap theory.

A. Energy Band in Solids:

During solid formation, the outer most energy levels of the atoms overlap with each other to form a band of energy. An energy band consists of closely spaced energy levels, which are considered to be continuous.

The outermost electrons of an atom are called valence electrons and the band of energy occupied by the valence electrons is known as valence band (V.B.) This valence band may be partially filled or completely filled but it cannot be empty. The next higher permitted band of energy is called the conduction band (C.B.). It is located above the valence band. The electrical conductivity of solids depends on the number of electrons present in the conduction band of their atoms. The conduction band may be empty or partially filled and can never be completely filled.

When the electrons reach the conduction band from the valence band, they can freely move, so they are called as free electrons or conduction electrons. These free electrons are responsible for flow of electric current through the solid. The gap between the valence band and the conduction band is called the forbidden energy gap (F.G.).

B. Energy band diagram for Conductors, insulators and semiconductors:

Our interest is focused on conducting property of a material. In general, physical and chemical properties of an element are decided by the valence orbital electrons. For example, if valence orbit is filled, with element is inert like He, Ne, etc. On the other hand the materials with unfilled valence orbit exhibit electrical and magnetic properties like metals. So, only valence band is considered for further studies. The other low level bands are not contributing any significant changes in the conducting properties.

The energy band occupied by the valence electrons is called valence band (V.B.). Next, the conducting band (C.B) lies above the valence band. Conduction band is due to the free electrons from the atoms of the crystal or solid. These free electrons possess kinetic energy and acts as a carrier within the crystal.

The energy band diagrams for good conductors, insulators and semiconductor are shown in the Figure 6.11.

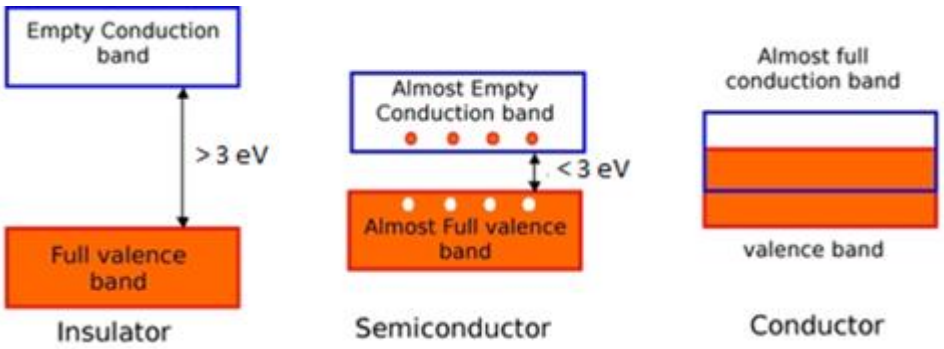


Figure 6.11: Band gap sizes of Insulator, semiconductor and conductor.

The above energy band diagram has a gap between V.B. and C.B, named as forbidden energy gap. So based on the energy gap between the valence band and conduction band, the materials are classified as conductors, semiconductors and insulators.

Conductors:

Conductors are materials with high conductivities ranging between 10^4 and 10^7 $ohm^{-1}m^{-1}$. Metals have conductivities in the order of 10^7 $ohm^{-1}m^{-1}$ are good conductors. In conductors, the lowest level in the conduction band happens to be lower than the highest level of the valence band and hence the conduction band and the valence band overlap. Hence the electron in the valence band can migrate very easily into the conduction band. Thus at a room temperature, a large number of electrons are available for conduction. Examples: Copper, Aluminum, Silver, Gold, All metals.

Characteristics of Conductors:

- The substances which conduct electricity through them in greater extent are called conductors.
- In conductors, the conduction band and the valence band overlap with each other or gap between them is very small. So, the forbidden energy gap is $E_g = 0$.
- There are free electrons in the conduction band.
- Due to increase in temperature conductance decreases.
- There is no effect of the addition of impurities on the conductivity of conductors.
- Their conductivity range between 10^4 and 10^7 $ohm^{-1}m^{-1}$.

Insulators:

Insulators are materials with very low conductivities ranging between 10^{-20} and 10^{-10} $ohm^{-1}m^{-1}$. The conduction band and valence band are widely spaced. Thus forbidden energy gap between the valence band and conduction bands is large (greater than 3eV). Hence the electrons in the valence band cannot migrate into the conduction band. Hence no electrons are available for conduction. But at higher temperature, some of the electrons from the valence band may gain external energy to cross the gap between the conduction band and the valence band. Then these electrons will move into the conduction band. At the same time, they will create vacant energy levels in the valence band where other valence electrons can move. Thus the process creates the possibility of conduction due to electrons in conduction band as well as due to vacancies in the valence band.

Examples: Glass, wood, paper, plastic, mica.

Characteristics of insulators:

- In insulators the conduction band and valence band are widely separated.
- There are no free electrons in the conduction band.
- There is energy gap between conduction band and valence band which is more than 3eV.

In insulators like diamond, the forbidden energy gap is quite large having a value is 6eV, so minimum of 6eV energy is required for electron to move from valence band to conduction band.

- There is no effect of change of temperature on the conductivity of insulators.
- There is no effect of the addition of impurities on the conductivity of insulators.
- They have very low conductivities ranging between 10^{-20} and 10^{-10} $ohm^{-1}m^{-1}$.

Semiconductors:

These are materials with conductivities in the intermediate range from 10^{-6} and 10^{4} $ohm^{-1}m^{-1}$. The forbidden energy gap between the valence band and the conduction band is less than 3eV. Thus energy gap between the valence band and conduction band is small. At absolute zero, no electrons are available for conduction. As the temperature increase, many electrons from the valence band may gain external energy to cross the gap between the conduction band and the valence band. Then these electrons will move into the conduction band. At the same time, they will create vacant energy levels in the valence band where other valence electrons can move. Thus the process creates the possibility of conduction due to electrons in conduction band as well as due to vacancies in the valence band.

In semiconductors, charges movement can be manipulated according to our need to make electronic devices. So, silicon and germanium are used as a base material for making electronic components like diode, transistors, etc.

Characteristics of semiconductors:

- In semiconductors, the conduction band and valence band are very close to each other or the forbidden energy gap between them is very small. The forbidden energy gap is 1.1 eV for Silicon
- The electrons of valence band can easily be excited to the conduction band.
- There is energy gap between conduction band and valence band which is less than 3 eV.
- Due to increase in temperature conductance increases.

- There is an effect of the addition of impurities on the conductivity of semiconductors.
- Their conductivity range from 10^{-6} and 10^{4} $ohm^{-1}m^{-1}$.

1. Intrinsic Semiconductors:

In general, semiconductors are classified as intrinsic and extrinsic semiconductors. Semiconductors in pure form are called intrinsic semiconductor. Example: A crystal formed by silicon atoms alone (see Figure 12). The silicon atoms are arranging themselves by sharing an electron between the neighboring atoms. Such bond is covalent bond.

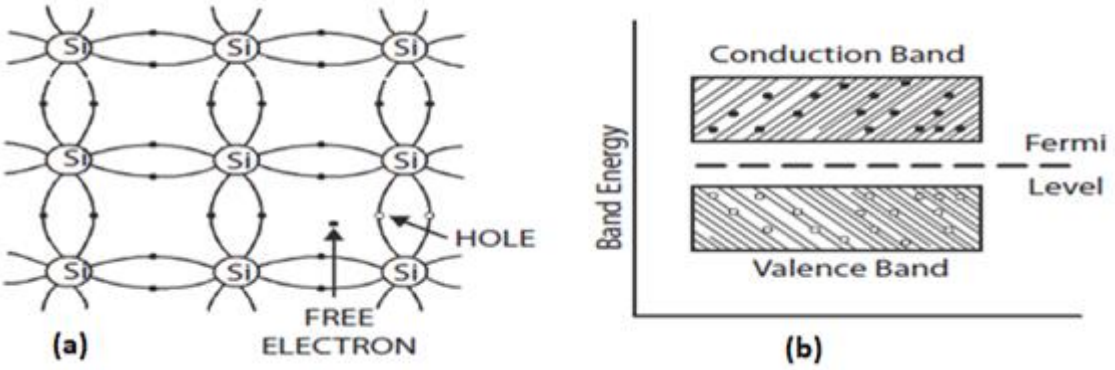


Figure 6.12: (a) Silicon in covalent bond and (b) Band gap in pure semiconductor

In intrinsic semiconductor like silicon forbidden energy gap value is 1.1 eV. This energy is available for semiconductors placed at room temperature. Due to that thermal energy some covalent bond within the crystal breaks (or) some electrons are pumped from valence band to conduction band. In the bond from which electron is freed, a vacancy is created there. This absence of electron is named as hole. Electron and hole pair is created. Thus at room temperature, a pure semiconductor will have both electrons and holes wandering in random directions. This electron and holes are called intrinsic carriers and such a semiconductor is called intrinsic semiconductor. The vacant place created in the valence band due to the jumping of electron from the valence band to conduction band is called 'hole', which is having positive charge.

Extrinsic semiconductor:

Pure semiconductor at room temperature possesses free electrons and holes but their number is so small that conductivity offered by the pure semiconductors cannot be used for any practical

purpose like device making. By the addition of certain selected impurities to the pure semiconductor in a very small ratio (1:106), the conductivity of a silicon or germanium crystal can be remarkably improved.

The process of adding impurity to a pure semiconductor crystal to improve its conductivity is named as doping. The impurity added semiconductors are named as extrinsic semiconductors. The extrinsic semiconductors are classified as P-type and N-type semiconductors, based on the type of impurity atoms added to the semiconductors.

N-type Semiconductor:

Pentavalent element like antimony (Sb) or arsenic (As) is added to pure silicon crystals. These impurity atoms replace some of the silicon atoms, here and there in the crystal. The added Arsenic (As) atom shares it four electrons with the neighbor atoms and release it fifth electron to the crystal for conduction. So these pentavalent elements are called donor impurities, as they donate electrons without creating holes.

In silicon, electron needs 1.1 eV to move from valence band to conduction band. This energy becomes available to the semiconductor even at room temperature. So at room temperature few covalent bonds within the material are broken by the thermal energy from the surrounding and some electrons from the valence band are pumped to conduction band. This process leaves some absence of electrons in the valence band. Electron and hole pairs are created. At the same time, the number electrons in the conduction band are increasing further by the addition of pentavalent impurities without any addition of holes which already exist within the crystal. So the numbers of electrons are donor electrons plus thermal electrons at room temperature. This thermal excitation produces very less pair of electrons and holes, whereas the added impurity donates more electrons. The majority charge carriers electrons are of the order of 1024, whereas the minority charge carriers holes are of the order of 108 at 300 K.

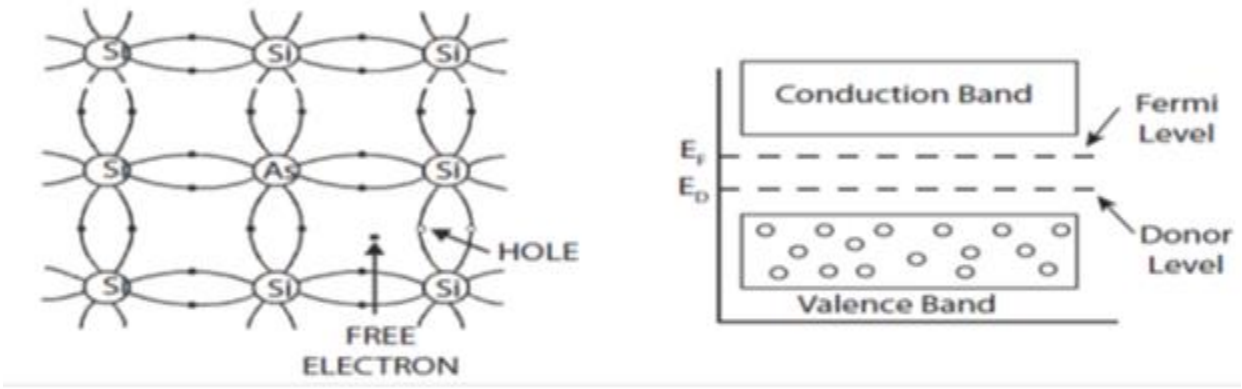


Figure 6.13: Dopped Arsenic atom in covalent bonding with Silicon atoms to form N-type semiconductor.

Hence, the majority charge carriers are electrons in this material (see Figure 6.13). The electron carries negative charge, so it is named as N-type semiconductor and conduction is due to large number of electrons. As the number of electrons in the conduction band is more than the number of holes in the valance band, in N type semiconductor, the Fermi level lies nearer to the conduction band.

P-type Semiconductor:

When trivalent element like Indium, Aluminum, Boron is doped with pure silicon, the added impurity atoms replace some of the silicon atoms, here and there in the crystal and establish covalent band with the neighboring atoms. Indium has three electrons but that Indium is covered by four silicon atoms as shown in the Figure 6.14. So, one of the covalent bonds is not completed by sharing of electrons between them. There is an absence of electron which creates a hole.

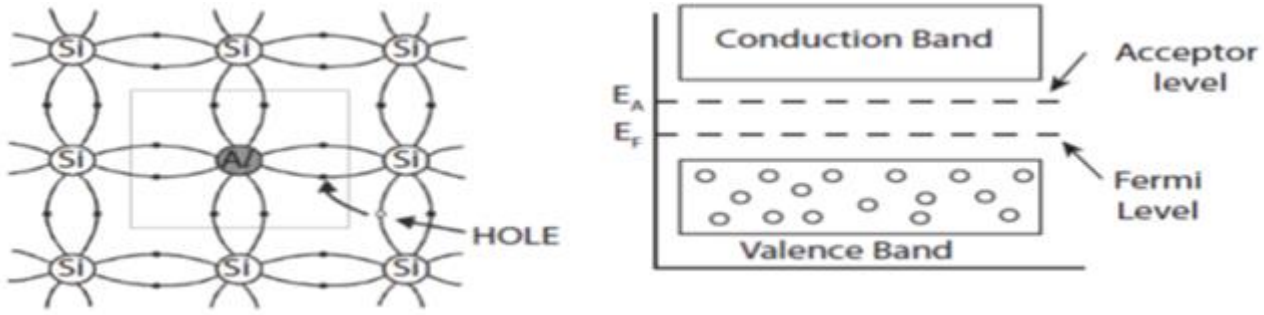


Figure 6.14: Dopped Aluminum atom in covalent bonding with Silicon atoms to produce P-type semiconductor

Indium needs one more electron to complete its covalent band. So indium is an acceptor of electrons. Now, this extrinsic semiconductor gains thermal energy from the surrounding at room temperature. So some electron absorbs this thermal energy and jumps to the conduction band.

This creates electrons and holes pair due to thermal excitation. So the total number of holes in the valance band is due to donor's atom plus thermally generated holes.

The holes are majority and electrons are minority. Hence conduction is due to majority charge carriers which are holes. Here the holes are behaving like positive charge carriers. So this material is named as P-type. As the number of holes in the valence band is more than the number of electrons in the conduction band, the Fermi level lies nearer to the valence band, in P type semiconductor.

6.9. Diodes

To understand electronic devices and circuits, brief idea about semiconductor diodes is must. The semiconductor diode is a fundamental two terminal electronic device, similar to a resistor. The volt–ampere (V-I) relationship of a resistor is linear. However, the V-I characteristic of a diode is not only nonlinear but also depends on the operating condition. That is resistor allow the charge carriers at any condition and behaves like passive element. A diode allows current to pass through it in one direction and acts as a switch in electronic circuits.

N junction diode:

At the room temperature, a piece of P-type material has majority of holes and N-type material has a majority of electrons. When a part of intrinsic semiconductor piece is doped with pentavalent impurities and the remaining part is doped with trivalent impurities, a P-N junction diode is formed.

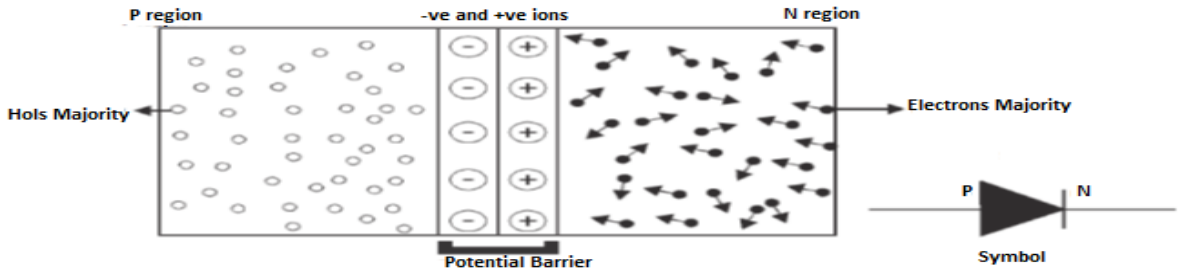


Figure 6.15: Diode and its schematic symbol.

Potential barrier and depletion region*:*

In the PN junction diode as shown in Figure 6.15, the P region has circles with a negative sign indicating immobile ions and the mobile holes are represented by small circle. In the N region, the circles with a positive sign inside represent immobile ions and the mobile free electrons are represented by small dots.

During the junction formation, the free electrons and holes on both sides of the junction migrate across the junction by the process of diffusion. The electrons passing through the junction from N region into the P region recombines with holes in the P region very close to the junction. Similarly, the holes crossing the junction from the P region into the N region recombine with the electrons in the N region very close to the junction. This recombination of free or mobile charges produces a narrow region on either sides of the junction of width about 10^{-4}cm to 10^{-6}cm. This region is called the depletion region, where there are no mobile charges available.

In the depletion region, the atoms on the left side of the junction become negative ions (-) and the atoms on the right side of the junction become positive ions (+).Thus an internal potential difference (p.d.) is produced across the junction. This p.d. is called the internal potential barrier. This prevents the further flow of charge carrier from P-region to N-region. The potential barrier for germanium is 0.3 V and that for silicon is 0.7 V. The potential barrier of a PN junction diode can be decreased or increased by applying external voltage. This barrier acts like a battery. However the value of potential barrier depends upon the number of diffused impurity atoms within the silicon crystal (or) depends upon the dopant concentration. The arrow mark or arrow-head represents holes current flow direction (Conventional Current flow direction), when they form a circuit with an external source.

Forward and Reverse biasing of P-N junction diode: Biasing:

Applying a suitable d.c. voltage to a diode is known as biasing. It can be done in two ways.

1. Forward Biasing:

When the positive terminal of the battery is connected to the P-type semiconductor and the negative terminal to the N-type semiconductor of the P-N junction diode (see Figure 6.16), the junction is said to be forward biased. When the applied voltage is increased from zero, the holes

and the electrons move towards the junction. Therefore the depletion layer is decreased and disappeared i.e., the potential barrier is disappeared.

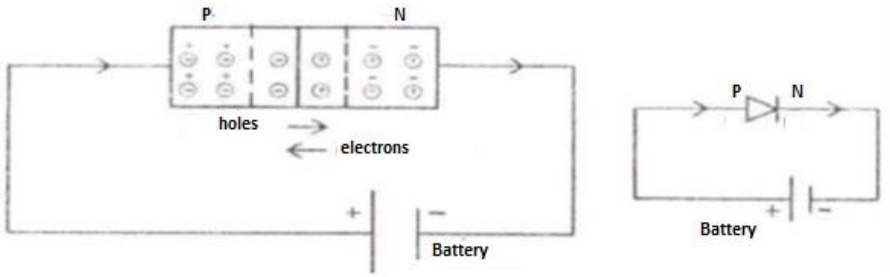


Figure 6.16: Diodes in forward bias

While the holes and the electrons move across the junction, they combine together and neutralized. Electrons from the battery move into the N-type semiconductor. Further they move the junction and come out of the P-type semiconductor. Hence there is a flow of current. The current is due to flow of electrons. Thus the P-N junction diode conducts electricity. As the battery v increases, the current also increases. The current is of the order of milli ampere (mA).

2. Reverse biasing:

When the negative terminal of the battery is connected to the P-type semiconductor and the positive terminal to the N-type semiconductor of the P-N junction diode, the P-N junction diode is said reverse biased. The negative potential of the battery attracts the holes. Similarly, the positive pot of the battery attracts the electrons. Therefore the holes and electrons move away from the junction (see Figure 6.7). Hence the width of the depletion layer increases and there is no current flow through the junction during reverse bias. However, as the reverse bias voltage increases, the minority charge carriers across the junction. Therefore there is a very feeble current, which is of the order of micro ampere (μA).

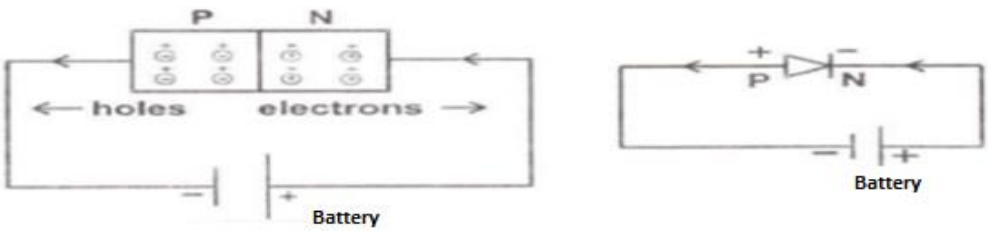


Figure 6.7: Diode in reverse bias

Diode acts as a switch. In forward biased state diode is in “ON” position and in the reverse

biased condition the same diode is in “OFF” position. So diode is an electronic device which allows the conventional current flow in one direction alone. Diodes can be used in a number of ways. For example, a device that uses batteries often contains a diode that protects the device if you insert the batteries backward. This diode simply blocks any current from leaving the battery if it is reversed. It protects the sensitive electronic devices.

P-N junction diode rectification:

A P-N junction diode conducts electricity when it is forward biased and it does not conduct electricity when it is reverse biased. Hence it is used to rectify alternating voltage (A.C). The process in which an AC voltage is converted into a unidirectional (D.C) voltage is known as rectification and the circuit used for the conversion is called a rectifier. In general, a rectifier is an electronic device which converts a.c. signal into d.c. signal. It is based on the principle that a junction diode offers low resistance path for input signal, when forward biased and high resistance under reverse biased condition.

Half - wave rectification:

The simplest kind of rectifier circuit is the half wave rectifier (Figure 6.18). When an A.C input is applied to a junction diode, it gets forward biased during the positive half cycle permitting the A.C input to pass through the load, and reverse biased for the negative half cycle during this time prohibiting the A.C input not to pass through the load.

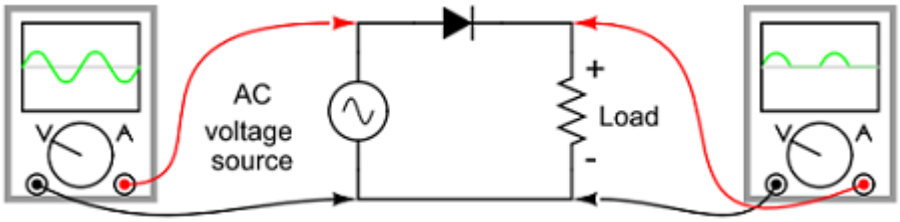


Figure 6.18: Half wave rectifier circuit.

The Full Wave Rectifier Circuit

If we need to rectify A.C power to obtain the full use of both half-cycles of the sine wave, a full wave rectifier circuit must be used. The popular full-wave rectifier circuit built around a four-diode bridge is called a full-wave bridge.

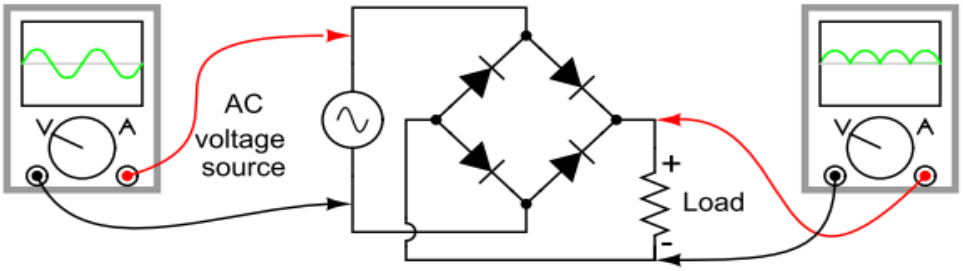


Figure 6.19: Full wave rectifier circuit.

Current directions for the full- wave bridge rectifier circuit are as shown in Figure 6.19 for positive half- cycle and for negative half-cycles of the AC source waveform. Note that regardless of the polarity of the input, the current flows in the same direction through the load. That is, the negative half-cycle of source is a positive half-cycle at the load (see Figure 20 & 21). The current flow is through two diodes in series for both polarities. Thus, two diode drops of the source voltage are lost in the diodes. This is a disadvantage compared with a full- wave center-tap design. This disadvantage is only a problem in very low voltage power supplies.

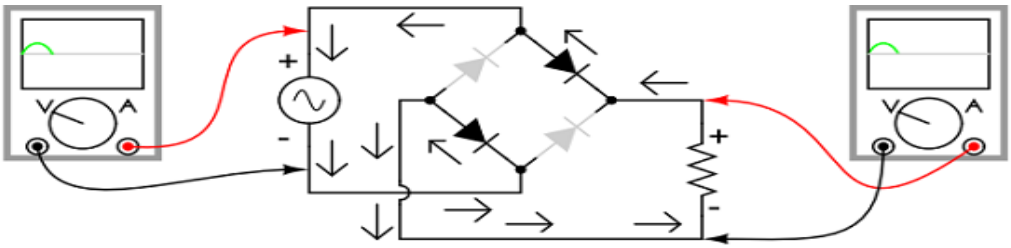


Figure 6.20: Full-wave rectifier circuit: Electron flow for positive half-cycles.

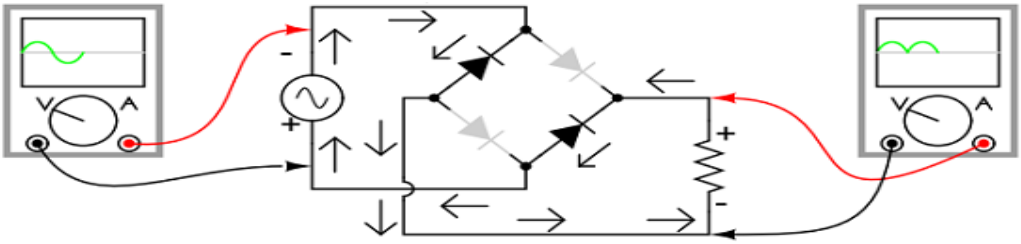


Figure 6.21: Full-wave rectifier circuit: Electron flow for negative half-cycles.

6.10. Transistors

A junction diode cannot be used for amplifying a signal. For amplification another type of semiconductor device called 'transistor' is used. Transistor is a three sectioned semiconductor.

Transistor is a solid state device. Two P-N junction diodes placed back to back form a three layer **transistors**.

Figure 6.22: The two types of transistors, NPN and PNP.

The three sections of the transistors are called emitter [E], base [B] and collector [C]. In a transistor the emitter is heavily doped, since emitter has to supply majority carriers. The base is lightly doped. Two type of transistors are available, namely N-P-N and P-N-P transistor (see Figure 6.22).

Symbol for transistors:

Figure 6.23: Symbols for PNP and NPN transistors.

In the symbolic representation for a transistor as shown in Figure 6.23, the arrow mark is placed on the emitter in the direction of conventional current flow, i.e., from P to N direction.

In an electronic circuit a transistor can be connected in three different ways (see Figure 6.24). They are,

(I) Common base (CB)

(ii) Common emitter (CE)

(iii) Common Collector (CC)

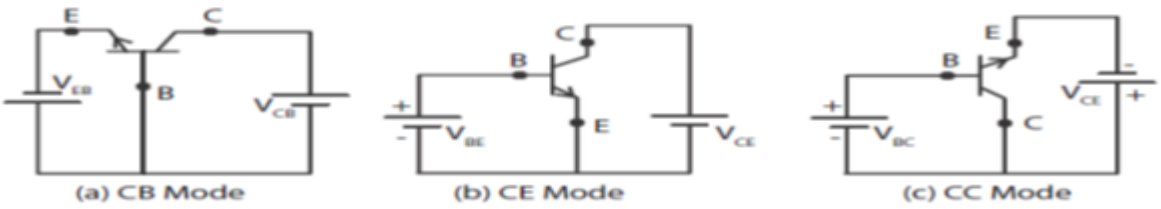


Figure 6.24: Transistor connections, (a) common base, (b) common emitter and (c) common collector

The term common is used to denote the lead that is common to the input and output circuits. The three different modes are shown above for NPN transistor. For proper working of a transistor, the input junction should be forward biased and the output junction should be reverse biased.

Self Diagnostic Question: ***Why do we need amplification?***

When we cannot hear a stereo system, we have to increase the volume, when picture in our television is too dark, we should increase the brightness control. In both of these cases, we are taking a relatively weak signal and making its stronger (i.e., increasing of its power). The process of increasing the power of an a.c. signal is called amplification. The circuit used to perform this function is called amplifier. An amplifier may also be defined as a device, which amplifies the input weak signal. The input signal may be obtained from a phonograph, tape head or a transducer such as thermocouple, pressure gauge etc.

Transistor Amplifier- Common Emitter configuration (NPN):

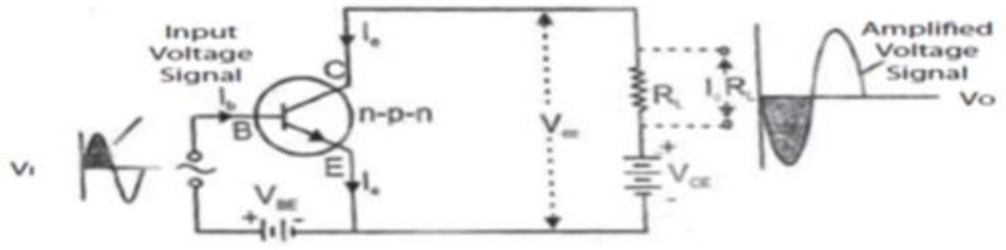


Figure 6.25: NPN transistor as an amplifier

Amplifier is an electronic device which is used to magnify the amplitude of weak signal. A common emitter configuration of NPN transistor amplifier circuit is shown in Figure 6.25. The potential V_{BE} with input AC signal V_i is applied between base and emitter and the potential V_{CE} is applied between collector and emitter through the load resistance RL. The output amplified signal voltage V_O is obtained between collector and emitter. The amplification of the transistor is explained by using its transfer characteristic curve shown in the figure. It gives the variation of collector current I_C with increase of base current I_b at constant V_{CE}.

$$\text{Current gain, } \beta = \frac{\Delta I_c}{\Delta I_b}$$

In common emitter configuration, the collector current is β times larger than the input base current. So the variation in I_C is much more than that in I_b. If the input signal rises, it increases the I_b from OP to OA and also there is a corresponding increase in I_C from PQ to AA'. If I_b decreases from OA to OP, I_C also decreases from AA' to PQ. Similarly it happens in reverse direction also as it continues an amplified sine wave form of I_C flows in the circuit. Both the frequencies of input and output are the same. If I_C increases the potential drop across RL also increases.

From circuit, $V_0 = V_{CE} - I_c R_L$.

As per the above equation, the increase of potential across RL opposes the V_{CE}. So that the input signal and the output voltage are out of phase differing by 180^0.

A.C. power gain:

It is the ratio of the change in output power to the change in input power.

$$\text{A. C. power gain} = \frac{Change\ in\ out\ power}{Change\ in\ input\ power}$$

$$= \left(\frac{\Delta I_c}{\Delta I_b}\right)^2 \frac{R_{out}}{R_{in}}$$

Example: In a common base connection, IE =1 mA, IC = 0.95 mA. Calculate the value of IB.

Solution:

Using the relation, $I_E = I_C + I_B$

$1 = I_B + 0.95$

$I_B = 1 - 0.95 = 0.05$ mA.

Example: Calculate IE in a transistor for which β = 50 and IB = 20 μA.

Solution

Here β=50, IB = 0.02 mA

Now, $\beta = \frac{I_C}{I_B}$

$\therefore IC = \beta I_B = 50 \times 0.02 = 1$ mA.

Advantages of common emitter configuration:

On comparing the three different configurations of an amplifier, with help of their characteristics like input impedance, output impedance, current gain, voltage gain, power gain and phase

reversal the following are the major advantages of common emitter configuration when compared with other configurations.

- High input impedance
- Low output resistance
- Moderate current gain
- High voltage gain
- High Power gain
- Phase reversal

In common emitter amplifier, the output signal is 180^0 out of phase with input signal.

Logic Gates:

Logic Gates: An electronic circuit which has one or more inputs but only single output is called agate. There is always logic relationship between input and output of a gate hence more precisely is called logic gate. Logic gates are basically of three types: (i) OR- gate, (ii) AND- gate and (iii) NOT - gate.

The input to a logic gate can have only one of two values. It can be low, example near 0 V, and indicatedby"0," or it can be high, example close to the supply voltage of typically 5-6 V, and indicated by "1."A truth table for a logic gate indicates the output for all possible inputs.

Different logic gates have different shapes and their type is sometimes written on them in circuit diagrams. The common logic gates and their truth table is provided as Figure 6.26 below:

- **AND** gate - output is only high when both inputs are high, otherwise the output is low. A and B is written as$A \cdot B$
- **NAND** (NOT AND) gate - logic output of any logic gate is reversed if the symbol is modified by adding a small circle to the base of the output. Output is low when both inputs are high. For all other combinations of input output is high.
- **OR** gate -logic output is high if either or both of the inputs are low. A or B is written $A + B$
- **NOR** (NOT OR) gate- logic output is the reverse of an OR gate.
- **NOT** gate - called an inverter since output is always the logical opposite to the input

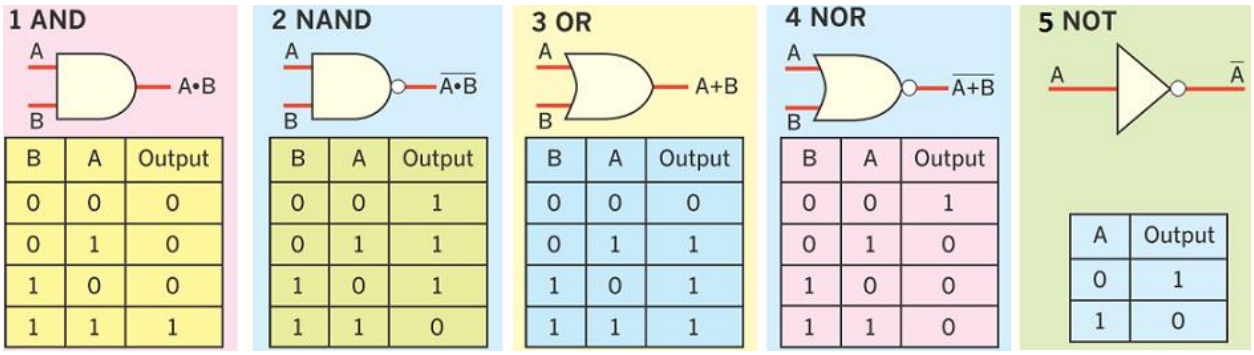


Figure 6.26: Symbols for different type of logic gates

Chapter Summary

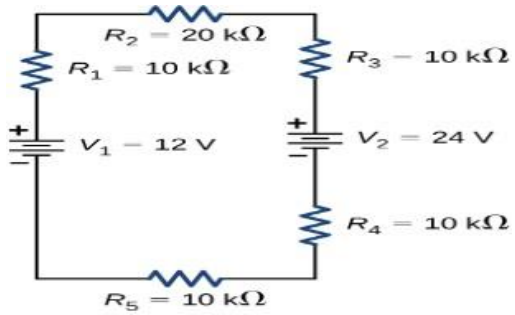
- Coulomb's law gives the magnitude of the force between point charges. It is given by

$$\vec{F}_{12}(r) = \frac{K|q_1 q_{21}|}{r_{12}^{\ 2}}\hat{r}$$

- The electric field mediates the electric force between a source charge and a test charge.
- Electric potential is potential energy per unit charge.
- The potential difference between points A and B, $V_B - V_A$, that is, the change in potential of a charge q moved from A to B, is equal to the change in potential energy divided by the charge
- Magnets have two types of magnetic poles, called the north magnetic pole and the south magnetic pole. North magnetic poles are those that are attracted toward Earth's geographic North Pole. Like poles repel and unlike poles attract.
- Discoveries of how magnets respond to currents by Oersted and others created a framework that led to the invention of modern electronic devices, electric motors, and magnetic imaging technology.
- Semiconductors are a class of materials which lie between insulators and metals (conductors). Pure semiconductors are two types: intrinsic (pure) and extrinsic (with impurity atoms). Adding a suitable impurity to a semiconductor is called doping. Doped semiconductors are either n-type or p-type.
- A p-n junction, consisting of wafers of p-type and n-type germanium or silicon may be either grown or fused, depending on manufacturing technique. A P-N junction diode conducts in forward direction and poorly in reverse direction.
- Rectifiers are used to convert alternating supply into dc supply. Since the electric energy that is available through power mains is alternating but the electric energy needed for most of the electronic gets is dc, we make use of the rectifier circuits.
- A junction transistor is a sandwich made up of two p-n junctions either in pnp form or npn form. Transistors can be used as amplifiers, rheostat, switches etc.

Chapter Revision Questions and Problems

1. Two balloons are charged with an identical quantity and type of charge: -0.0025 C. They are held apart at a separation distance of 8 m. Determine the magnitude of the electrical force of repulsion between them.
2. A particle of charge 2 x 10^{-8}C experiences an upward force of magnitude 4 x 10^{-6} N when it is placed in a particular point in an electric field.
   A. What is the electric field at that point?
   B. If a charge q = -1.0 x 10^{-8} C is placed there, what is the force on it?
3. What is the strength of the electric field between two parallel conducting plates separated by 1.00 cm and having a potential difference (voltage) between them of 1.5V?
4. Consider the circuit shown below. (a) Find the voltage across each resistor. (b)What is the power supplied to the circuit and the power dissipated or consumed by the circuit?



5. A rectangular coil of dimensions 5.40 cm x 8.50 cm is by a magnetic field of magnitude of 0.350T parallel to the plane of the loop. What is the magnetic flux on the rectangular loop?
6. A proton moves with a speed of 8.0 x 10^6 m/s along the x-axis. It enters a region where there is a field of magnitude 2.5 T, directed at an angle of 60^0 to the x-axis and lying in the xy plane. Calculate the initial magnetic force and acceleration of the proton.
7. A proton is moving in a circular orbit of radius 14 cm in a uniform magnetic field of magnitude 0.35 T directed perpendicular to the velocity of the proton. Find the orbital speed of the proton.
8. A stationary coil is in a magnetic field that is changing with time. Does the emf induced in the oil depend on the actual values of the magnetic field?

CHAPTER SEVEN

CROSS CUTTING APPLICATIONS OF PHYSICS

"**Imagination is more important than knowledge**" ….Albert Einstein

Self Diagnostic Test

- Why do we need to study Physics?
- What are the roles of physics in science and technology?

Physics is the most fundamental and all-inclusive of the sciences, and has had a profound effect on all scientific development. In fact, it is the present-day equivalent of what used to be called *natural philosophy*, from which most of our modern sciences arose. Physics generates fundamental knowledge needed for the future scientific and technological advances that will continue to drive the economic engines of the world. And also it contributes to the technological infrastructure and provides trained personnel needed to take advantage of scientific advances and discoveries. Students of many fields find themselves studying physics because of the basic role it plays in all phenomena.

Physics is the curiosity-driven study of the inanimate natural world at a very fundamental level that extends across all nature; from the extremes of empty space itself, time, light, energy, elementary particles, and atoms through many orders of magnitude to stars, galaxies, and the structure and fate of the universe. Physics is widely appreciated for the beauty of its concepts, but it is valued for its immense range of predictive power and life-improving application.

Successive revolutions in fundamental physics have been tightly interconnected with technological advances that have each substantially improved our lives. The concepts, laws, principles, and theories of physics are widely applicable in the following scientific and technological areas.

- ***Newtonian mechanics*:** Industrial revolution based on engineered machines; probably the closest to our daily experiences, Newtonian mechanics finds many applications in

industry as well as research. Mechanical design and automation in industry and simulation in research rely on the principles of classical mechanics.

- ***Thermodynamics:*** Steam engines to power machines, railroads, steamboats;

- ***Electricity and magnetism: E***lectrical power distribution system, motors, lights, telegraphs, electronics; development in the knowledge of Electricity and Magnetism has revolutionized the technological development in all fields of physics. The generator and motor designed using the phenomena of Electromagnetic Induction are widely used machines. Technology and industry today depends largely on power. Knowledge of magnetism has helped us build precise instruments and mechanical systems.

- ***Quantum mechanics:*** Lasers, atomic clocks, chemistry;

- ***Nuclear Science****:* finds many different applications in diverse fields of science and technology; Atomic energy, medical diagnosis and treatments, production of electricity in nuclear power plants. The study of structure of molecules can be carried out by a technique called Nuclear Magnetic Resonance which uses the phenomena of Nuclear Magnetic Resonance (NMR) and derives its name from it. NMR uses the magnetic property of the nucleus.

- ***Condensed matter physics:*** Transistors and integrated circuits, computers, materials like liquid crystals (e.g., liquid-crystal displays), polymers, superconducting technology and materials;

- ***Optics*****:** Optics and Optical phenomena find many examples in nature such as the formation of the rainbow, the phenomenon of mirage and twinkling of stars. There are many other applications of optics using lens systems, mirrors, fiber optics, lasers and diffraction gratings etc. The field of fiber optics is advanced and still a large amount of research is going on in fiber optics. This field is useful in communication systems. The field of ray optics is used to design and use the Microscope, the Telescope and cameras. Optics is also used in the design of precision components and systems.

The beauty of this intellectual approach and its remarkable profusion of insights, knowledge, and applications has captured the imaginations of people for centuries and attracted them to study, research, and develop applications in physics.

Learning Objectives: At the end of this chapter students will be able to:

- Explain the application of physics in different sciences and technology fields.
- Provide an insight to students on how physics played in the development of one's nation (Science and technology)
- Describe the physical properties of the soil and their effects on soil quality.
- Analyze how the principle of electromagnetic induction is applied on Generator and Motor operations
- Explain the basic principles of the major medical imaging techniques;
- Help students become more literate in the benefits and hazards of radiation.
- Discuss the uses of radiation and radioactive particles in archeology, industry, and medicine.
- Stimulate students on the understanding of Seismometer, Radio and TV communications.
- Discuss the physics concepts behind the renewable sources of energies

7.1. Physics in Agriculture and Environment

Agro physics is one of the branches of natural science dealing with the application of physics in agriculture and environment. It plays an important role in the limitation of hazards to agricultural entities (soils, plants, agricultural products and foods) and to the environment. Soil physical degradation, gas production in soils and emission to the atmosphere, physical properties of plant materials influencing their technological and nutritional values and crop losses are examples of such hazards. Agro physical knowledge can be helpful in evaluating and improving the quality of soils and agricultural products as well as the technological processes.

Soil is the upper most layer of earth crust, and it supports all terrestrial life. It is the interface between the lithosphere and the atmosphere, and strongly interacts with biosphere and the

hydrosphere. It is a major component of all terrestrial ecosystems, and is the most basic of all natural resources. Most living things on earth are directly or indirectly derived from soil.

Soil physics deal with the study of soil physical properties (e.g., texture, structure, water retention, etc.) and processes (e.g., aeration, diffusion, etc.). It also consists of the study of soil components and phases, their interaction with one another and the environment, and their temporal and spatial variations in relation to natural and anthropogenic or management factors (Figure 7.1). Additionally, soil physics involves the principles of physics to understand interrelationship of mass and energy status of components and phases as dynamic entities.

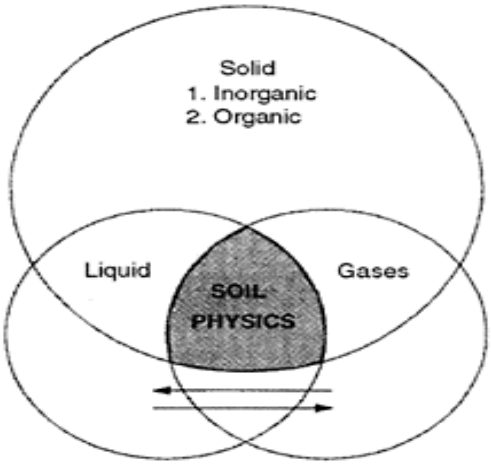


Figure 7.1: The three phases of Soil. Under optimal conditions for growth of upland plants, the solid phase composes about 50% of the total volume, and liquid and gaseous phases each compose 25% by volume.

Soil quality plays an important role in agriculture, more specifically, it is directly related to soil physical properties and processes which affects agronomic productivity through strong influences on plant growth. There is a misconception and a myth that agricultural productivity can be sustained by addition of fertilizer and/or water. Expensive inputs can be easily wasted if soil physical properties are suboptimal or below the critical level. High soil physical quality plays an important role in enhancing soil chemical and biological qualities. Applications of soil physics can play a crucial role in sustainable management of natural resources (Fig. 7.2). Soil physical properties such as soil texture, structure, water retention and transmission, heat capacity and thermal conductivity, soil strength, etc are important to agricultural sustainability. These properties affect plant growth and vigor directly and indirectly.

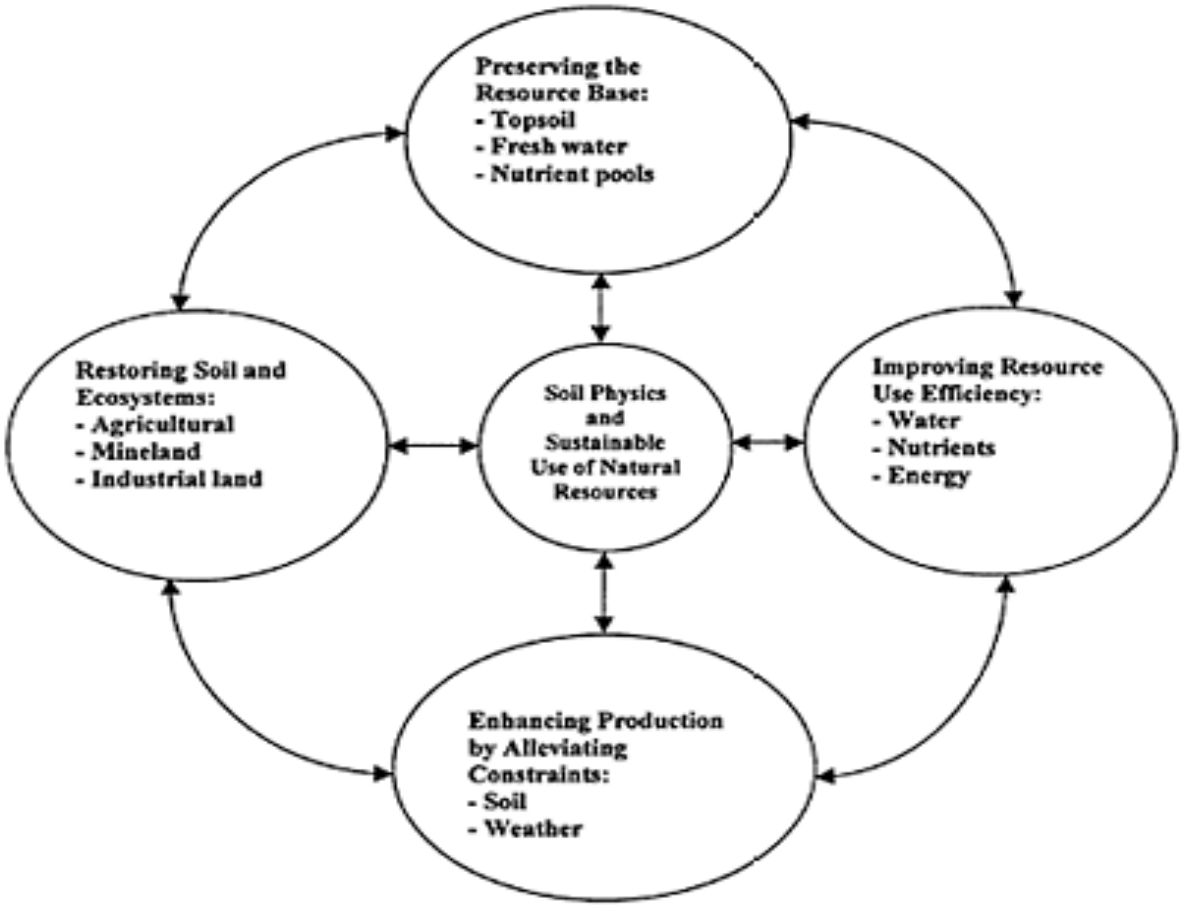


Figure 7.2: Applications of soil physics are crucial to sustainable use of natural resources for agricultural and other land uses.

Soil Density*:* is the relation between the mass and the volume of a dry soil sample. It is commonly expressed in the units of g/cm^3 and Kg/m^3. This density is defined in the following four ways: *particle density, bulk density, relative density or specific gravity and dry specific volume.*

Soil Porosity*:* refers to the relative volume of voids or pores, and is therefore expressed as a fraction or percent of the total volume or of the volume of solids. Soil porosity can be expressed in the following four ways: *total porosity, air-filled porosity, void ratio and air ratio.*

Soil Moisture Content

Soil moisture is the term used to denote water contained in the soil. Soil water is usually not free water, and is, therefore, called soil moisture. Soil moisture content can be expressed in the following four ways: g*ravimetric soil moisture content, volumetric soil moisture content, liquid ratio, degree of saturation.*

Energy Balance Concept and Energy Balance in Soil

The surface energy balance is usually defined with respect to an active layer of very small thickness of the soil. In this case the storage of energy in the layer can be neglected and the energy balance equation is written mathematically as:

$$0 = R_n + G + LE + H \quad \ldots\ldots\ldots\

7.2. Physics in Industries

Principles of Motor and generator

One of the important applications of electromagnetism is the electric motor. A motor is a machine that converts electrical energy into mechanical energy. A generator does exactly the opposite: it converts mechanical energy into electrical energy. Electric motors generate magnetic fields with electric current through a coil. The magnetic field then causes a force with a magnet that causes movement or spinning that runs the motor.

DC Motor and its Principles of Operation

The dc motor is a mechanical workhorse that can be used in many different ways. Many large pieces of equipment depend on a dc motor for their power to move. The speed and direction of rotation of a dc motor are easily controlled. This makes it especially useful for operating equipment, such as winches, cranes, and missile launchers, which must move in different directions and at varying speeds. The operation of a dc motor is based on the following principle: A current-carrying conductor placed in a magnetic field, perpendicular to the lines of flux, tends to move in a direction perpendicular to the magnetic lines of flux. There is a definite relationship between the direction of the magnetic field, the direction of current in the conductor, and the direction in which the conductor tends to move.

GENERATORS

A generator is a machine that converts mechanical energy into electrical energy by using the principle of magnetic induction. This principle is explained as follows: Whenever a conductor is moved within a magnetic field in such a way that the conductor cuts across magnetic lines of flux, voltage is generated in the conductor. The AMOUNT of voltage generated depends on (1) the strength of the magnetic field, (2) the angle at which the conductor cuts the magnetic field, (3) the speed at which the conductor is moved, and (4) the length of the conductor within the magnetic field. The POLARITY of the voltage depends on the direction of the magnetic lines of flux and the direction of movement of the conductor.

7.3. Physics in Health Sciences and Medical Imaging

The contribution of physics to medicine and health science can be described at various levels. Much could be written about the impacts of basic discoveries of physics on medicine, which is, among other descriptors, an applied science. One example is the discovery of x-ray diffraction, which led to the knowledge of the three-dimensional structures of molecules that was crucial to understand biology at the molecular level with important impact on such areas as pharmacology and genetic diseases. Medical practice utilizes a broad range of devices that contain microelectronics. In fact, diagnostic imaging modalities, such as x-ray, Computer tomography scanner, magnetic resonance imaging, and ultrasound have been revolutionized medical practices**.**

Radiation is all around us. And it is naturally present in our environment and has been since before the birth of this planet. Radiation can also be produced artificially, as in medical x-rays and microwaves for cooking. It can be either beneficial or harmful, depending on its use and control. Therefore, regulation of certain radioactive sources is necessary in which people protect themselves from unnecessary or excessive exposures.

Radiation is energy given off by matter in the form of rays or high-speed particles. There are many forms of radiation that are familiar to us. For example, we use light, heat, and microwaves every day. Radiation can be thought of as the transmission of energy through space and it may be classified as electromagnetic or particulate, with electromagnetic radiation including visible light, infrared and ultraviolet, X rays and gamma rays (Fig. 7.3), and particulate radiation including electrons, positrons, protons and neutrons.

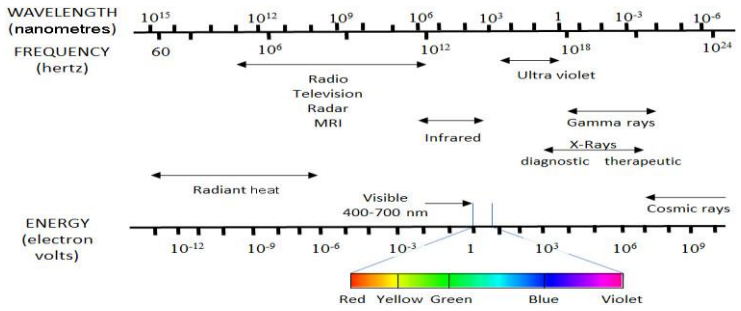


Figure 7.3: The electromagnetic spectrum. MRI: magnetic resonance imaging.

Radiation: is classified as ionizing or non-ionizing, depending on its ability to ionize matter (Figure 4):

- Non-ionizing radiation cannot ionize matter and has longer wavelength/lower frequency

lower energy.

- Ionizing radiation has higher energy/short wavelength/high frequency and sufficient energy to produce ions in matter at the molecular level. It ionize matter either directly or indirectly:
- *Directly ionizing radiation*: Fast charged particles that deposit their energy in matter directly, through many small Coulomb (electrostatic) interactions with orbital electrons along the particle track.
- *Indirectly ionizing radiation*: X or gamma ray photons or neutrons that first transfer their energy to fast charged particles released in one or a few interactions in the matter through which they pass. The resulting fast charged particles then deposit their energy directly in the matter.

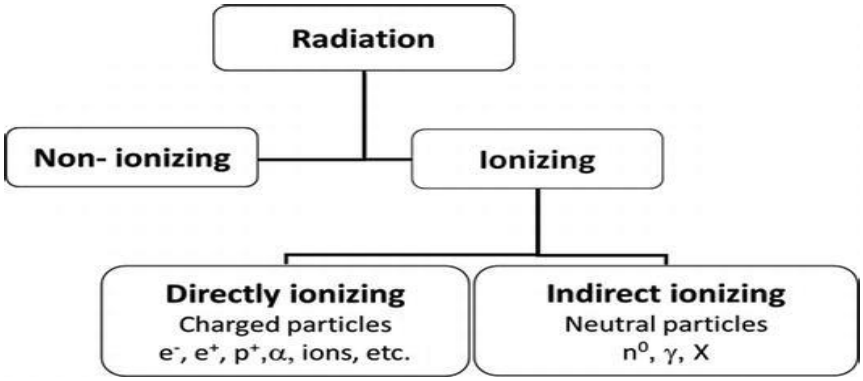


Figure 7.4: Classifications of Radiation

Biological effects of radiation

Self diagnostic question: *What happens when living things are exposed to radiation?*

Consequently, life has evolved in an environment which has significant levels of ionizing radiation. It comes from outer space (cosmic), the ground (terrestrial), and even from within our own bodies. It is present in the air we breathe, the food we eat, the water we drink, and in the construction materials used to build our homes. Ionizing radiation has enough energy to electrically charge or ionize matter. The cells in living organisms are also made of matter, so they too can be ionized. Cosmic rays, x-rays, gamma rays, alpha particles and beta particles are forms of ionizing radiation. Ionizing radiation may come from a natural source such as the Sun or it may come from a man-made source such as an x-ray machine. The possibility of

overexposure to ionizing radiation among members of the general public is minimal. However, there are environments such as hospitals, research laboratories and areas of high level natural background radiation where some potential health risks do exist. The effect of ionizing radiation on the human body or any other living organism depends on three things:

1. The amount and the rate of ionizing radiation which was absorbed.
2. The type of ionizing radiation which was absorbed.
3. The type and number of cells affected.

There are three primary means of reducing radiation dose from sources external to the body: *time, distance,* and *shielding*.

For a given source of radiation, the amount of radiation energy deposited in the body is related to how long one is exposed. Therefore, reducing the duration of an individual's exposure to radiation will decrease dose. Increasing the distance between an individual and a radiation source is an important means of reducing radiation exposure, because the intensity of the radiation is inversely proportional to the square of the distance from the radiation source. Shielding is useful for absorbing radiation energy. If enough interactions occur in the shielding material, then much of the radiation is prevented from reaching the body's tissues. Alpha particles can be stopped by a piece of paper. Beta particles are blocked by about a centimeter of plastic. Clothing and the outer layers of skin cells provide some protection from beta particles outside the body. Gamma rays, however, may require many centimeters of lead or meters of concrete for shielding.

Medical Imaging

Medical imaging refers to several different technologies that are used to view the high-resolution, 2 or 3 dimensional images of the human body to diagnose, monitor, or treat medical conditions. It is one of the most remarkable fields that have transformed the face of clinical medicine during the last millennium. Imaging technologies include radiography, magnetic resonance imaging (MRI), nuclear medicine, photo acoustic imaging, tomography, ultrasound, echocardiography, etc. A medical image is a pictorial representation of a measurement of an object or function of the body.

X-Ray: use ionizing radiation to produce images of a person's internal structure by sending X-ray beams through the body, which are absorbed in different amounts depending on the density of the material. X-rays are potentially harmful, and should be used with care. X-rays, however, have higher frequency and shorter wavelength than light and radio waves. An X-ray tube consists of two electrodes, one negative, and glow cathode, which upon being heated emits electrons, and one positive, anode. The electrodes are incapsuled in a vacuum. By applying an acceleration potential (20-200 kV), the electrons are accelerated towards the anode. The electrons gain kinetic energy which is the product of their charge and the potential difference. As a measure of the kinetic energy of the electrons and X-ray photons, the unit of 1eV is used.

Computerized Tomography (CT Scanner): It is a medical imaging method that combines multiple X-ray projections taken from different angles to produce detailed cross-sectional images of areas inside the body. CT images allow to get precise, 3-D views of certain parts of the body, such as soft tissues, the pelvis, blood vessels, the lungs, the brain, the heart, abdomen and bones. CT is often the preferred method of diagnosing many cancers, such as liver, lung and pancreatic cancers;

Magnetic Resonance Imaging (MRI): is a spectroscopic imaging technique used in medical settings to produce images of the inside of the human body and uses radio waves and a magnetic field to create detailed images of organs and tissues. MRI has proven to be highly effective in diagnosing many conditions by showing the difference between normal and diseased soft tissues of the body.

ULTRASOUND

Sound is a mechanical form of energy. A vibrating source is responsible for the production of sound. The number of vibrations per unit time, called the *frequency* of vibrations, determines the quality of the sound produced. The sound spectrum can be conveniently divided into three distinct parts. *Audible sounds* are those which can be perceived by the human ear. There are some differences between individuals in their ability to perceive sound frequencies. In most humans, the audible frequency range is approximately 20 Hz - 20,000 Hz. Sound which has a frequency below that which can be perceived by the human ear is referred to as *infrasound***,** while sound of frequencies higher than that of human perception is known as *ultrasound***.**

Therefore, ultrasound may be defined as sound energy of frequency higher than 20 kilohertz (20 kHz).

Ultrasound Systems: Diagnostic ultrasound, also known as medical sonography or ultrasonography, uses high frequency sound waves to create images of the inside of the body. The ultrasound machine sends sound waves into the body and can convert the returning sound echoes into a picture. Ultrasound technology can also produce images of internal organs and structures, map blood flow and tissue motion, and provide highly accurate blood velocity information to assess patient's health;

Ultrasound is the most commonly used diagnostic imaging modality, is an acoustic wave with frequencies greater than the maximum frequency audible to humans, which is 20 kHz
Ultrasound has a wide range of medical applications:

- Cardiac and vascular imaging
- Imaging of the abdominal organs
- *In utero* imaging of the developing fetus

7.3. Physics and Archeology

Radioactive Dating

Radiocarbon dating is an important tool for the determination of the age of many samples and covers the time period of approximately the last 50,000 years. We can use radiocarbon dating to estimate the age of a wide variety of carbon-containing materials. Both organic and inorganic materials at the Earth's surface and in the oceans form in equilibrium with atmospheric carbon-14. This makes it an important tool for the understanding of processes during the time-scale of modern humans, from the last glacial-interglacial transition, to recent archaeological studies of art works. We present an overview of the technique, its advantages, assumptions and limitations. We also emphasize dating interesting objects. Radiocarbon has been applied to dating many historical artifacts and archaeological applications

The technique of radiocarbon dating was introduced by Willard Libby and his colleagues in the University of Chicago in 1950. Libby was awarded a Nobel Prize in 1960 for his work on ^{14}C, which reflects the revolutionary effect of radiocarbon dating in the scholarly community.

Archaeologists have long used carbon-14 dating (also known as radiocarbon dating) to estimate the age of certain objects. Traditional radiocarbon dating is applied to organic remains between 500 and 50,000 years old and exploits the fact that trace amounts of radioactive carbon are found in the natural environment.

Standard carbon-14 testing, as used by archaeologists, is based on the natural process of radioactive carbon formation that results from cosmic ray bombardment of nitrogen in the earth's upper atmosphere. The radioactive carbon is taken from the atmosphere and incorporated into plant tissues by plant photosynthesis. It is then incorporated into all living organisms by means of the food chain. After an organism dies, its level of carbon-14 gradually declines at a predictable pace, with a half-life of about 5,730 years. Archaeologists precisely measure levels of the isotope in organic remains. Knowing the half-life, they back calculate how much time must have passed since the remains had levels identical to living organisms. Radiocarbon measurement can date organic remains up to about 50,000 years old. Objects younger than 500 years old are rarely radiocarbon dated. Natural and anthropogenic fluctuations in environmental radiocarbon levels mean that organisms living in different centuries within the past 500 years can have identical radiocarbon contents.

Radiocarbon in nature

Radiocarbon (^{14}C) is a naturally occurring isotope of carbon formed in the upper atmosphere by the interaction of cosmic radiation with nitrogen atoms (Figure 7.5). It is unstable, with a half-life of 5730 ± 40 years. Once produced, radiocarbon quickly enters the terrestrial food chain by photosynthesis, and so the ^{14}C content of all living organisms is in equilibrium with that of the contemporary atmosphere. When an organism dies it ceases to take up radiocarbon, and so over time the proportion of ^{14}C in the dead organism decreases. By measuring the proportion that remains, the elapsed time since death can be estimated. The ratio of ^{14}C in the material of unknown age to that in a modern standard is multiplied by the half-life to determine the age.

There are three physical characteristics of radiocarbon that make it particularly difficult to measure. First, the naturally occurring concentration of radiocarbon in living material is extremely low. The three isotopes of carbon occur in the proportions ^{12}C: ^{13}C: $^{14}C = 1: 0.01: 1.2 \times 10^{-12}$. This makes detecting a radiocarbon atom in a sample at the limit of detection (about 50

000 years old) equivalent to identifying a single specific human hair that might occur on the head of any of the human beings alive on earth today!

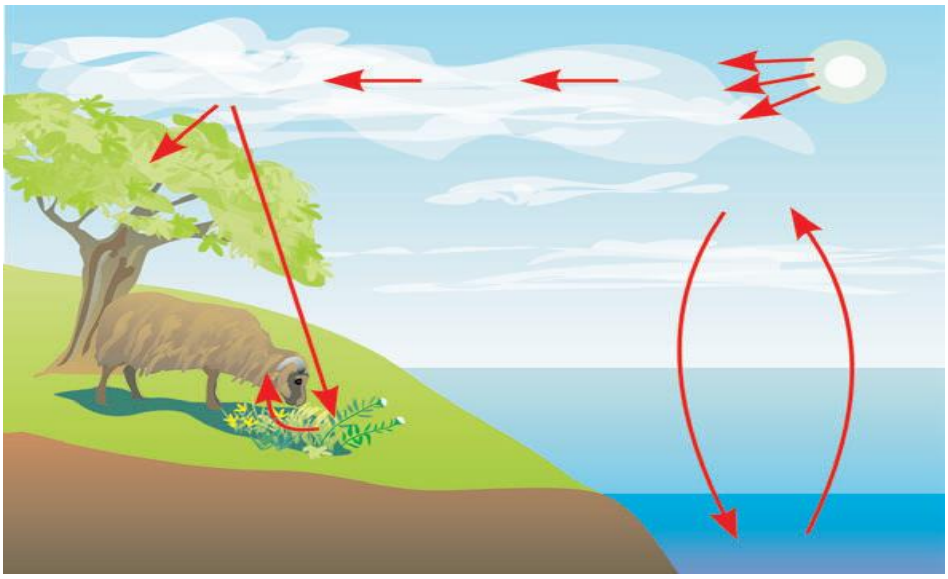


Figure 7.5: 14C is formed in the upper atmosphere. Cosmic rays produce neutrons which collide with 14N nuclei ($14N + n \rightarrow {}^{14}C + p$).

Second, the natural radioactivity of carbon is extremely low (226±1 Bq kg^{-1} or 13.56 decays per minute per gram of carbon). This is within the range of natural background radiation on the Earth's surface, which makes distinguishing ^{14}C radioactivity difficult. Third, the energy of the electrons emitted by the decay of radiocarbon is very low, and so they are difficult to detect. Radiocarbon disintegrates as follows:

$$14C \rightarrow 14N + \beta^{-} + \bar{\nu}.$$

Where the reaction energy is distributed over the escaping electron ($\beta -$) and the antineutrino ($\bar{\nu}$). The maximum energy of the β^{-} particle is as low as 156 keV. Further difficulties arise because the energies held by electrons produced by the decay of radiocarbon overlap with the energy spectrum produced by other decay products of contaminant radioisotopes, specifically radon and tritium (222Rn and 3H).

Radiocarbon in archaeological samples

For accurate radiocarbon dating, only the ^{14}C that was part of the organism when it died should be measured. Therefore the first task is to remove any foreign carbon that has entered the sample since that time. Such contamination comes principally from the burial environment.

This is done by a mixture of physical and chemical means. A simplified outline of one of the pretreatment protocols is given in Figure 7.6. The procedures also isolate a stable chemical fraction of a sample for dating (e.g. cellulose from wood).

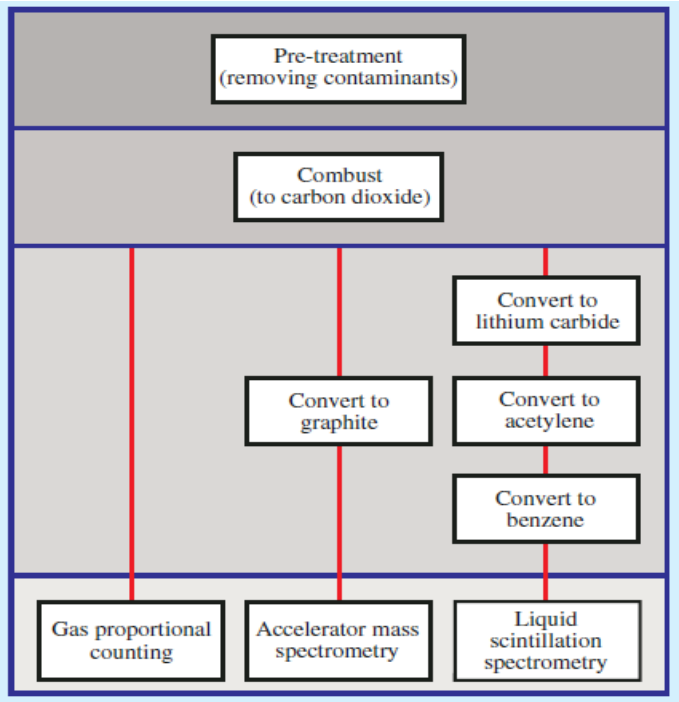


Figure 7.6: An overview of methods for measuring radiocarbon in archaeological samples.

Radiocarbon (^{14}C) is produced in the upper atmosphere by the action of secondary cosmic-ray particles, which are thermal neutrons on nitrogen. It has a half-life of 5,700 years and the amounts of ^{14}C produced naturally cover the time scale of approximately 50,000 years. Of course, this is also the period of interest to archaeology and many other fields. There are a large and diverse number of applications of ^{14}C.

Radiocarbon dating relies on a basic assumption that organic or inorganic materials are in equilibrium with ^{14}C, which is produced in the atmosphere and its removal into other reservoirs, and which establishes a constant level of ^{14}C at any given time. This relies on the radioactive decay equation (Rutherford and Soddy 1902), where the decay rate is determined by the number of atoms:

$$\frac{N}{N_0} = e^{-\lambda t}$$

When an animal or plant dies, it is removed from the atmospheric equilibrium and so the level of ^{14}C decays is obtained from the apparent "radiocarbon age" or *t*. Rearranging this equation:

$$t = -\lambda \ln(\frac{N}{N_0})$$

Where N is the number of atoms, N_0 is the number of atoms present at the time of formation of the material and λ is the decay constant of the nuclide. This "radiocarbon age" is an approximate age of the material, since there are other effects on the ^{14}C production in the atmosphere.

7.4. Application in Earth and Space Sciences

Seismometer

Seismology provides the only direct method for measuring the properties of the deep interior of our planet. Seismometers are the sensors that produce the signal to be recorded. Modern seismometers produce some voltage that is related to the ground motion by the instrument response. The earliest seismometers consisted of a mass, a spring, and sometimes a damper. The mass was usually very large since its motion was typically measured by a series of levers that caused a needle stylus to move over a rotating drum covered with smoked paper. Thus it was necessary for the small motions of the ground to cause enough momentum in the mass to overcome the friction of the recording system. Seismic sensors are the mechanical or electromechanical assemblies that convert Earth motion into electrical signals that can then be digitized and recorded for later analysis.

TV and Radio Communications

Satellites offer a number of features not readily available with other means of communications. Because very large areas of the earth are visible from a satellite, the satellite can form the star point of a communications net, simultaneously linking many users who may be widely separated geographically. Satellites are also used for remote sensing, examples being the detection of water pollution and the monitoring and reporting of weather conditions. Some of these remote sensing satellites also form a vital link in search and rescue operations for downed aircraft and the like.

Satellites are specifically made for telecommunication purpose. They are used for mobile applications such as communication to ships, vehicles, planes, hand-held terminals and for TV and radio broadcasting.

A satellite works most efficiently when the transmissions are focused with a desired area. When the area is focused, then the emissions do not go outside that designated area and thus minimizing the interference to the other systems.

Radio

Radio is one of the important inventions of the 20th Century, which has changed the overall meaning of the term mass communication. The parallel changes in technology have made the radio more powerful in terms of the impact they have upon masses. Radio reaches almost everyone everywhere. Radio involves the process, by which the messages are sent through electrical waves. In other words, sound would be sent and received through the waves Radio waves are produced by the accelerated motion of charges in conducting wires. They are used in radio and television communication systems. They are generally in the frequency range from 500 kHz to about 1000 MHz. The AM (amplitude modulated) band is from 530 kHz to 1710 kHz. Higher frequencies upto 54 MHz are used for *short wave* bands. TV waves range from 54 MHz to 890 MHz. The FM (frequency modulated) radio band extends from 88 MHz to 108 MHz. Cellular phones use radio waves to transmit voice communication in the ultrahigh frequency (UHF) band.

A radio transmitter converts electrical energy into electromagnetic radiation. The transmission medium for electromagnetic wave propagation is free space. Signals within the audio frequency band do not travel very far if converted directly to electromagnetic waves. Instead, the audio signal is used to vary (modulate) some characteristics, such as amplitude or frequency, of a high frequency radio wave, known as a carrier wave. Because of its high frequency, the carrier wave is able to propagate over very large distances and therefore carry the audio signal much further without the need for repeated amplification. The un-modulated carrier wave conveys very little information itself. It is simply on or off.

Radio bands

Electromagnetic waves shown in Figure 7.7 with frequencies in the range 30 kHz to 300 GHz are used for radio, TV, and satellite communication. For convenience, the range is divided up into the following bands.

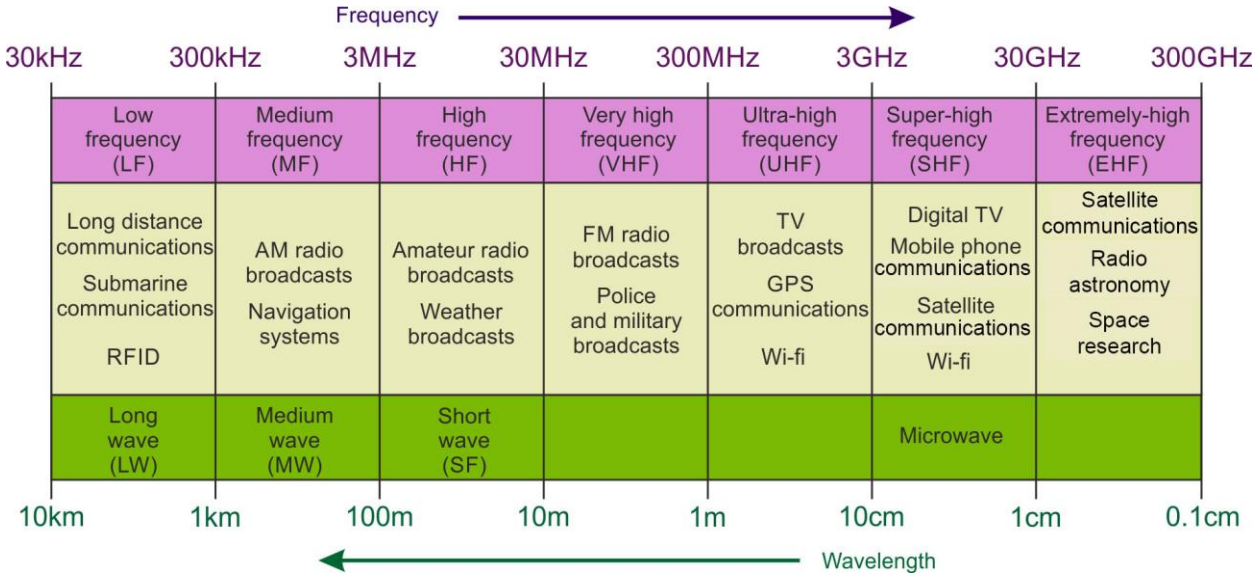


Figure 7.7: Frequency bands and electromagnetic waves

Radio waves can travel from location to location in a number of ways, dependent on their frequency. At frequencies below 3 MHz, radio waves follow the contour of the earth's surface (shown in Figure 7.8) and are referred to as surface waves or *ground waves*. With sufficient transmitter power, they can travel for thousands of kilometers. This method of propagation occurs mainly in AM radio broadcasting and amateur radio.

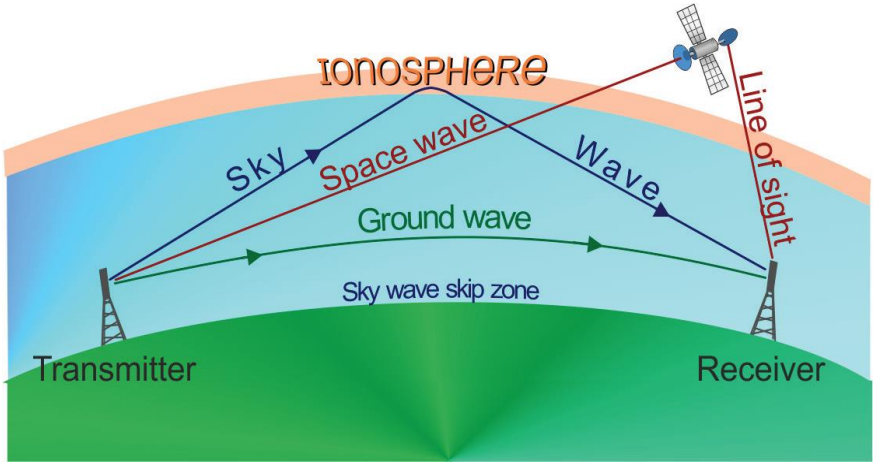


Figure 7.8: Surface / ground waves

- **Sky waves:** At frequencies in the range 3 to 30 MHz, radio waves travel upwards, towards space, and are reflected back towards the earth by the ionosphere. In doing so, they create *dead* or *skip* zones at the Earth's surface, where the signal cannot be picked up.
- **Space waves:** Waves with frequencies above 30 MHz travel in straight lines and are used in:
  - Terrestrial 'line of sight' communication links i.e. where the receiving aerial can be 'seen' from the transmitting aerial;
  - FM radio broadcasts use frequencies between 87 and 110 MHz;
  - Television broadcasts use the UHF band - frequencies between 470 and 850 MHz;
  - Mobile phone networks use frequencies in the range 450 to 2100 MHz;
  - Line of sight microwave systems use frequencies in the range 2 to 80 GHz to carry long distance telephone traffic, television channels and data up to a distance of about 50 km. A network of repeater stations is used to give nationwide coverage;
  - Satellite communication systems, using frequencies in the range 1 to 300 GHz, for global positioning systems (GPS), voice and video transmission, satellite TV, radio astronomy and space research.
- **Microwaves:** Microwaves (short-wavelength radio waves), with frequencies in the gigahertz (GHz) range, are produced by special vacuum tubes (called klystrons, magnetrons and Gunn diodes). Due to their short wavelengths, they are suitable for the radar systems used in aircraft navigation. Radar also provides the basis for the speed guns used to time fast balls, tennis serves, and automobiles.

7.5. Applications in Power Generation

Energy plays a very important role in our lives, providing comfort, increasing productivity and allowing us to live the way we want to. Since the beginning of mankind, we have made use of wood, water, and fossil fuels as a means of heating and making machines work. Almost for all types of activities, we rely on one or another form of energy. Amount of energy used by a society is an indicator of its economic growth and development. Without energy even our body would be unable to perform basic functions like respiratory, circulatory, or digestive functions to name a few. Nowadays, the electrical energy has become so important that almost in all walks of life electricity is required. For example all electrical appliances in our homes and at our

workplace require electricity. All the industries and factories run on electricity. There is a variety of sources that provide us energy for different purposes.

Fossil Fuels – Conventional Source of Energy

A fossil fuel is a fuel formed by natural processes, such as anaerobic decomposition of buried dead organisms, containing energy originating in ancient photosynthesis. Fossil fuels contain high percentages of carbon and include petroleum, coal, and natural gas. Coal, crude oil and natural gas are common examples of fossil fuels. They are used to run the vehicles, cooking, lighting, washing, to generate electricity, for making plastics and paints etc.

Table 7.1: Advantages and disadvantages of fossil fuels

Advantages	**Disadvantages**
Provide a large amount of thermal energy per unit of mass	Nonrenewable
Easy to get and easy to transport	Burning produces smog
Can be used to generate electrical energy and make products, such as Plastic, paints etc.	Burning coal releases substances that can cause acid precipitation
	Risk of oil spills
	High cost

Energy from the Atom – Nuclear Energy

Nuclear power is the use of nuclear reactions that release nuclear energy to generate heat, which most frequently is then used in steam turbines to produce electricity in a nuclear power plant. Nuclear power can be obtained from nuclear fission, nuclear decay and nuclear fusion. The atoms of a few elements such as radium and uranium act as natural source of energy. In fact atoms of these elements spontaneously undergo changes in which the nucleus of the atom disintegrates. The energy stored in the nuclei of atoms can be released by breaking a heavy

nucleus such as uranium into two lighter nuclei. The splitting of the nucleus of an atom into fragments that are roughly equal in mass with the release of energy is called nuclear fission.

When a free neutron strikes a Uranium (235) nucleus at a correct speed, it gets absorbed. A Uranium (235) nucleus on absorbing a neutron becomes highly unstable and splits into nuclei of smaller atoms releasing huge amount of energy in the process. During this process, a few neutrons are also released. These neutrons split other nuclei of the Uranium (235). The reaction continues rapidly and is known as the chain reaction. In this process a large amount of energy is released. This energy is used for boiling water till it becomes steam. Steam so generated is used to drive a turbine which helps in generating electrical energy.

Table 7.2: Advantages and disadvantages of nuclear energy

Advantages	**Disadvantages**
Very concentrated form of energy	Produces radioactive waste
Power plants do not produce smog	Radioactive elements are nonrenewable

Table 7.3: Advantages and disadvantages of solar energy

Advantages	**Disadvantages**
Almost limitless source of energy	Expensive to use for large scale energy production
Does not produce air pollution	Only practical in sunny areas
	It is intermittent in nature

Sun - The Ultimate Source of Energy

Solar energy is energy derived from sun in the form of solar radiation. It is hardness by either direct sources (like solar cooker, solar steam systems, solar dryer, solar cells, etc.), or indirect sources (biomass production, wind, tidal, etc.). The output of the sun is 2.8×10^{23} Kwy^{-1}. The energy reaching the earth is 1.5×10^{8} Kwy^{-1}. It is used for drying, cooking, heating, generating power etc.

Wind Energy

Self diagnostic question: *Where does wind come from?*

Wind power is another alternative energy source that could be used without producing by-products that are harmful to nature. Wind is caused by the uneven heating of the atmosphere by the Sun, the irregularities of the Earth's surface, and rotation of the Earth. Like solar power, harnessing the wind is highly dependent on weather and location. However, it is one of the oldest and cleanest forms of energy and the most developed of the renewable energy sources.

Table 7.4: Advantages and disadvantages of wing energy

Advantages	**Disadvantages**
Renewable	Only practical in windy areas
Relatively inexpensive to generate	Produces less energy
Does not produce air pollution	Wind mill is big, bulky and inconvenient to use as compared to other forms of energy

Geothermal Energy

Geothermal energy is the heat from the Earth and the energy derived by tapping the heat of the earth itself like volcano, geysers, hot springs (etc.). These volcanic features are called geothermal hotspots. Basically a hotspot is an area of reduced thickness in the mantle which expects excess internal heat from the interior of the earth to the outer crust. The heat from these geothermal hotspots is altered in the form of steam which is used to run a steam turbine that can generate electricity.

Ocean Tidal and Wave energy

Tidal power or tidal energy is a form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity.

- **Wave energy** also known as ocean energy is defined as energy harnessed from oceanic waves. As the wind blows across the surface of the ocean, it creates waves and thus they can also be referred to as energy moving across the surface of the water

- **Tides** are defined as the rise and fall of sea level caused by the gravitational pull of the moon and the sun on the Earth. They are not only limited to the oceans, but can also occur in other systems whenever a gravitational field exists.
- **Ocean thermal energy (OTE)** is the temperature differences (thermal gradients) between ocean surface waters and that of ocean depths. Energy from the sun heats the surface water of the ocean. In tropical regions, surface water can be much warmer than deep water. This temperature difference can be used to produce electricity and to desalinate ocean water

Table 7.5: Advantages and disadvantages of geothermal energy

Advantages	**Disadvantages**
Reliable	High cost of investment
Sustainable	Emission of greenhouse gases during extraction of heat from ground
Environmentally friendly	
Abundant Supply	

Table 7.6: Advantages and disadvantages of ocean energy

Advantages	**Disadvantages**
Running cost is negligible	Low efficiency
Continuous power supply	High installation cost

Hydropower

Hydropower (from the Greek word *hydor,* meaning water) is energy that comes from the force of moving water. The fall and movement of water is part of a continuous natural cycle called the **water cycle**. As people discovered centuries ago, the flow of water represents a huge supply of **kinetic energy** that can be put to work. Water wheels are useful for generating motion energy to grind grain or saw wood, but they are not practical for generating electricity. Water wheels are

too bulky and slow. **Hydroelectric power plants** use modern turbine generators to produce electricity, just as thermal (coal, natural gas, nuclear) power plants do, except they do not produce heat to spin the turbines.

How a Hydropower Plant Works

A typical hydropower plant is a system with three parts:

- a power plant where the electricity is produced;
- a dam that can be opened or closed to control water flow; and
- a reservoir (artificial lake) where water can be stored.

To generate electricity, a dam opens its gates to allow water from the reservoir above to flow down through large tubes called **penstocks**. At the bottom of the penstocks, the fast-moving water spins the blades of turbines. The turbines are connected to generators to produce electricity (Shown in Figure Below). The electricity is then transported via huge transmission lines to a local utility company.

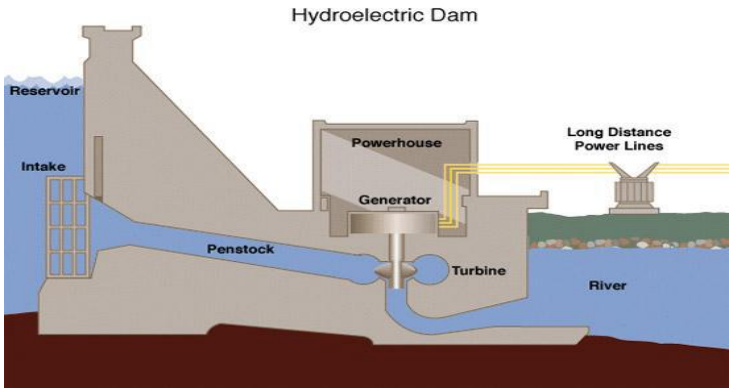


Figure 9: Hydroelectric Dam

As water flows from a high potential energy (high ground) to lower potential energy (lower ground), the potential energy difference thereby created can be partially converted into kinetic, and in this case electric, energy through the use of a generator.

Chapter Summary

Physics generates fundamental knowledge needed for the future scientific and technological advances that will continue to drive the economic engines of the world. And also it contributes to the technological infrastructure and provides trained personnel needed to take advantage of scientific advances and discoveries.

Agro physical knowledge can be helpful in evaluating and improving the quality of soils and agricultural products as well as the technological processes.

One of the important applications of electromagnetism is the electric motor. A motor is a machine that converts electrical energy into mechanical energy. A generator does exactly the opposite: it converts mechanical energy into electrical energy. Electric motors generate magnetic fields with electric current through a coil.

The contribution of physics to medicine and health science can be described at various levels.

The impacts of basic discoveries of physic on medicine, which is, among other descriptors, an applied science; the discovery of x-ray diffraction is example for this. Medical practice utilizes a broad range of devices that contain microelectronics. In fact, diagnostic imaging modalities, such as x-ray, Computer tomography scanner, magnetic resonance imaging, and ultrasound have been revolutionized medical practices**.**

Radiation is classified as ionizing or non-ionizing. Our life has evolved in an environment which has significant levels of ionizing radiation. It comes from outer space (cosmic), the ground (terrestrial), and even from within our own bodies. It is present in the air we breathe, the food we eat, the water we drink, and in the construction materials used to build our homes. Ionizing radiation has enough energy to electrically charge or ionize matter.

Radiocarbon dating is used to estimate the age of a wide variety of carbon-containing materials.

Energy plays a very important role in our lives, providing comfort, increasing productivity and allowing us to live the way we want to.

All the industries and factories run on electricity. There is a variety of sources that provide us energy for different purposes.

Chapter Review Questions

1. What is Soil Texture?
2. What factors affect soil permeability?
3. Explain the difference between AC and DC motors?
4. On what principle electric motor works?
5. How many types of electric motors are there?
6. Which of the following is most responsible for nuclear medicine imaging?

   A. Proton

   B. Neutrino

   C Neutron

   D X-ray
7. Radiation safety and protection, including:
   A. Radiation safety and emergency measures in radiotherapy
   B. Compliance with local legislative and licensing requirements, code of practice and local rules
   C. Room shielding design and calculation for radiotherapy equipment and facilities
   D. Optimization
8. What is radioactivity and why is it dangerous?
9. What are the sustainable energy sources?
10. What are the major electrical systems in hydropower plant?

COURSE PROGRESS EVALUATION FOCUS

Course evaluation will be through feedback received from students in the lecture, tutorial programs and test results and through an anonymous student survey which should be conducted every month.

KEY STUDENT-RELATED POLICIES

Students should read the module and/or reference materials and do the assignments on time. Practice with solved problems and come to office hours to get concepts clarified. Review and extra problems will be given through worksheets. Students are also expected to have worked through the problems in the worksheets before the tutorial sessions. Attendance at lectures and Laboratory is expected for all students. Attendance records will be taken at all times. It is the students chance to ask questions, solve problems and work in team.

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